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DRAFT FINAL REPORT

DEVELOPMENT OF CONSTRUCTION SITE

NOISE PARAMETERS AND LEVELS DATA BASE

February 1980

SCIENCE APPLICATIONS, INC.

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DRAFT FINAL REPORT

DEVELOPMENT OF CONSTRUCTION SITE NOISE PARAMETERS AND LEVELS DATA BASE

February 1980

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SUMMARY

This report presents the results of an investigation to: 1) identify additional pieces of equipment (generic types) not included in the EPA's construction site health and welfare noise impact model; 2) estimate the population density variations resulting from population transfer between the five construction site model geographical regions during the normal daytime work period; 3) evaluate construction activity duration time periods (and the influence of geographical location within the U.S. and of population density on the average construction activity duration); and 4) collect and evaluate available data concerning "typical", or average, noise-reduction values for various building-structure types.

Twelve pieces of construction equipment were identified as possible additions to the impact model. However, based on a selection criteria which related the equipments' typical use, source of power, and operational noise level to potential overall community noise exposure, only two pieces of construction equipment were selected for additional analyses and data collection. These pieces of equipment are: 1) manually-guided compactors; and 2) forklift trucks. From a construction site field survey, usage data for both pieces of equipment were obtained. These data included: 1) identification of the phases of construction during which the equipment was used; 2) typical number of hours of equipment operation per day; 3) estimated number of days during each phase that the equipment was actually operated; and 4) estimated percentage of each site type employing each equipment type. Based on these four data elements, equipment usage factors were determined. A detailed description of the data requirements and computational procedures used to determine the equipment usage factors is presented in Appendix A. In addition to usage factors, the total number of forklift trucks and manually-guided compactors used in construction was estimated to be 53,752

and 11,877, respectively. The average A-weighted noise level at 50 feet for both equipment types was determined from publications collected for a previous EPA literature search study. Although the relative change in total noise impact resulting from the addition of both equipment types to the impact model was not determined, the change in the site noise level at a reference distance of 50 feet for each site type was computed. The noise for the residential sites increased by 1.1 dBA while the other three sites increased by approximately 0.1 dBA.

The percent change in baseline population density values resulting from normal daytime work period population transfer was determined for each of the SMSA region categories considered in the EPA's construction site noise impact model. A detailed description of the computational procedures used to determine these percent changes is presented in Appendix B. Although the analysis was based on population data for SMSAs of 250,000 people or more, it is believed that the results are representative of the average population density variations for each of the five SMSA region categories. In general, the percent change in population density values derived from this study do not agree with the current baseline values. However, with the exception of the urban fringe region category, the two sets of population density values agree with respect to the relative direction of population transfer between SMSA region categories. With respect to the urban fringe region category, it was found that for the normal daytime work period, the net population decreased around high-density urban centers but increased around low-density urban centers. However, on the average, (data for both urban center types combined) the net population transfer for this region was almost negligible.

The current baseline population density values were revised to reflect the population transfers between SMSA region categories (derived from this study) and to reflect the population transfers within each SMSA region category where each type of construction activity is typical performed. The assumptions and a discussion of the procedure used to determine the revised population density values are presented in Appendix C.

The duration of construction activity for residential, office/public service, and industrial/commercial site types were investigated. The influence of geographical location of the site type within the U.S. and of surrounding population density on the average construction activity duration time period were also evaluated. It was found that for residential site types, the weighted-average construction activity duration time period (i.e., length of time from start to completion of the building project) does not vary significantly with respect to geographical location within the U.S. For office/public service and industrial/commercial site types, no data were available to determine the relationship between activity duration and geographical location. Based on local construction activity data and census tract population density values, the relationship between average population density and duration of construction activity, for all site types considered, has a low degree of correlation. Appendix D presents a complete listing of the data used to evaluate these relationships.

Compared with the data currently used in the construction site noise impact model, the study results show that the average (on a national basis) number of 8-hour days of construction activity for the residential and industrial/commercial site types may be underestimated by approximately 38 percent and 27 percent, respectively. For the office/public service site types, the construction activity duration may be overestimated by approximately 6 percent. Some uncertainty in these comparisons exists due to the assumption made regarding the percentage of construction activity "down-time" used in determining the average number of 8-hour days of construction activity. Down-time is defined as the percentage of the construction project start-to-completion time period during which no construction activity occurs.

Based on an evaluation of currently available data concerning "typical" or average building noise-reduction values, it appears that all construction site noise impact calculations should be performed relative to an L_{dn} outdoor threshold of 65 dB. The suggested use of a 65 dB outdoor threshold for all impact calculations is based on the finding that a representative average building noise-reduction value of 20 dB is applicable to single-family dwellings as well as other larger and heavier building-structure types.

1. INTRODUCTION

1. INTRODUCTION

1.1 BACKGROUND

The Noise Control Act of 1972 (P.L. 92-574, 86 Stat. 1234) established, by statutory mandate, a national policy "to promote an environment for all Americans free from noise that jeopardizes their health and welfare." As specified in the Noise Control Act of 1972, the first step towards promulgation of noise standards for new products is identification of those products that are major sources of noise.

Section 6(a)(1)(c) has identified construction equipment as one of four product categories to be considered for noise regulation. In determining whether a particular type of construction equipment is a major noise source and, therefore, subject to regulatory action, a health and welfare impact assessment is an essential and necessary consideration. To provide a quantitative assessment of the noise impact, a construction site model was developed to compute the number of people (on a national average) exposed to higher levels than the defined thresholds identified as requisite to protect the public health and welfare with an adequate margin of safety. The initial data base used in the development of this model was presented in a report prepared for the EPA in December 1971.[1] However, this report was incomplete in that some of the basic data sources were not identified and some of the computational procedures were unclear. Subsequent studies provided updates and revisions to some of the critical data elements but there is still a need to fill existing data gaps, to provide additions to the existing data base, and to revise obsolete or poorly documented assumptions. The objectives of this study are to provide data which can be used for these purposes.

1.2 STUDY OBJECTIVES

The principal objectives of this study are to: 1) identify additional pieces of equipment (generic types) not included in the EPA's construction site health and welfare noise impact model; 2) estimate the population density variations resulting from population transfer between the five construction site model geographical regions during the normal daytime work period; 3) evaluate construction activity duration time periods (and the influence of geographical location with U.S. and of population density on the average construction activity duration); and 4) collect and evaluate available data concerning "typical", or average, noise-reduction values for various building-structure types. Relative to each of these study objectives, this report will attempt to fill existing data gaps, to provide additions to the existing data bases, and to revise obsolete or poorly documented assumptions currently used in the EPA's construction site noise impact model.

2. IDENTIFICATION OF ADDITIONAL PIECES OF CONSTRUCTION EQUIPMENT

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2.1 EQUIPMENT IDENTIFICATION AND DESCRIPTION

2.1.1 Equipment Selection Procedure and Criteria

Based on a review of construction equipment buyers' guides, equipment manufacturers' literature, published reports dealing with construction equipment, and observations from previous construction site field surveys, several pieces of construction equipment, not included in the EPA's noise impact model, were identified. These additional equipment types included the following:

- Compactors, manually guided
- Forklift Trucks
- Mobile Concrete Mixing and Batching Plants
- Earth Augers
- Concrete Finishing Machines
- Mobile Crushing and Screening Plants
- Blowers and Fans
- Benders, Cutters and Threaders
- Drop Hammers
- Surface Grinders
- Muckers
- Pile Puller (Extractors)

The implicit objective of this study was to identify additional pieces of construction equipment which were typically used in the four types of construction considered in EPA's impact model, and therefore, would potentially contribute to the overall community noise exposure. Many of the above machine types were eliminated from consideration since they did not meet this typical use criterion. In addition, some of the machines were deleted on the basis that, although they may be typically used, they are only employed for very short periods of time during a single construction phase.* Also, some machines were omitted because: 1) they produce relatively low operational noise levels or, 2) their source of power was previously identified by EPA as a major source of construction site noise. Based on the above selection criteria, two pieces of construction equipment were identified for additional analyses and data collection. These pieces are: 1) compactors, manually guided, and 2) forklift trucks.

2.1.2 Equipment Description

Compactors, manually guided — There are two general types of manually guided compactors — rammer and vibratory plate. Both are generally powered by a relatively small gasoline engine ranging from approximately 2 to 16 horsepower. However, both are available with alternative power sources including electric and hydraulic motors and diesel engines. Although both types of compactors are used for the same purpose, i.e., surface compaction, the type of compactor required depends on the type of material to be compacted. For example, granular soils require a vibratory plate compactor while clay soils require the use of a rammer type compactor. Either a vibratory plate or rammer can be used on sandy or silt loam. A general description of the types and uses of gasoline engine powered, manually guided compactors is presented in Table 2-1.

Forklift Trucks — Construction site forklift trucks are specialized materials-handling machines. They are highly maneuverable, self-propelled units available in several mast configurations: 1) straight, 2) rear-mounted reach, 3) combination reach-and-mast, and 4) convertible lift/crane version. They are extremely versatile

*The EPA construction site model assumes that construction activities are performed during five discrete periods or phases. The time duration of each phase depends on the type of construction performed.

Table 2-1. GENERAL TYPES AND USES OF MANUALLY-GUIDED GASOLINE ENGINE POWERED COMPACTORS

Type of Compactor	Engine HP Range	Typical Compactor Uses: Compaction Materials	Typical Compactor Uses: Specific Work Tasks
Rammer	2.2-6.5 (2-cycle engines)	Cohesive soil, clay or loam	1. Large pipeline trench and underground electric, gas, water and telephone utility line backfill compaction.
Vibratory Plate	3.0-16.0 (4-cycle engines)	Granular soil, sand, crushed stone or gravel and other non-cohesive materials	2. Compaction around retaining walls, embankments, subgrades, abutments, foundations and asphalt patch work.*

*Vibratory plate compactors only.

machines used for lifting, moving, and spotting materials throughout a cluttered construction site, and are capable of placing materials and supplies as high as three stories. They are typically used on single and multiple unit residential housing sites as well as large construction projects such as hospitals, shopping malls and office buildings to handle lumber, support beams and trusses, gypsum board and masonry materials such as brick, concrete blocks (cinder blocks), and mortar. Construction forklift trucks are generally powered by a single gasoline or diesel engine with a horsepower rating typically less than 100 hp. The maximum lifting capacity and lifting height ranges from 2,000 to 10,000 lbs. and from 8 to 30 feet, respectively. Engine horsepower, lifting capacity, and lifting height are generally higher for the convertible lift/crane forklift types.

2.2 EQUIPMENT USAGE DATA REQUIREMENTS

EPA's construction site model includes four construction site types: 1) residential, 2) office/public service, 3) industrial/commercial, and 4) public works. It is assumed that all construction activities occur during five discrete time periods or phases. These phases and the associated time periods for each site type are identified in Table 2-2. A critical data element in determining

Table 2-2. HOURS OF CONSTRUCTION BY SITE TYPE AND CONSTRUCTION PHASE

Site Type \ Construction Phase	CONSTRUCTION PHASE				
	Clearing	Excavation	Foundation	Erection	Finishing
Residential	56	56	92	184	92
Office/Public Service	80	320	320	480	160
Industrial/ Commercial	80	320	320	480	160
Public Works	12	12	24	24	12

noise impact from each site type is related to the individual construction phase durations. This data element is the equipment usage factor which is defined as the ratio of the total time a single piece of equipment operates in a given phase to the total phase duration. The usage factor is then used to compute the daily equivalent noise level, $L_{eq}(8)$, for each machine type. This level is determined using the following relationships:

$$[L_{eq}(8)]_{ki} = L_k - 10 \log_{10}(T_i) + 10 \log_{10} [\sum_{l}(t_l UF_{kli})] \qquad (1)$$

where L_k = work-cycle equivalent noise level at 50 feet for equipment type k, db

T_i = total construction time for site type i, hours,

t_l = construction time for phase l, hours,

UF_{kli} = usage factor for equipment type k, phase l, and site type i.

The term (t_l UF_{kli}) in Equation (1) is simply the number of hours of usage on site type i for machine type k during construction phase l.

Knowing the number of hours of equipment use by phase for each construction site type and the total number of construction sites for each type, other relevant data can be derived. For example, with these data, the average annual hours of use for a specific equipment type can be determined if the total number of machines used in construction is known. Conversely, the number of machines used in construction can be determined if the machine's average annual hours of use are known. The importance and use of these relationships will be discussed in more detail in Section 2.4.

2.3 DATA OBTAINED FROM CONSTRUCTION SITE FIELD SURVEY

A construction site field survey was conducted to obtain relevant usage data for the two pieces of construction equipment discussed in Section 2.1, manually guided compactors and forklift trucks. Data were obtained at 43 construction sites; 20 residential, 18 office/public service, four industrial/commercial and one public works. These data were supplemented by information obtained during a similar field survey conducted prior to this study. Detailed usage data were collected for 23 of the construction sites surveyed. These data included: 1) the identification of the phases of construction during which each equipment type was used, 2) the typical number of hours of operation per day, and 3) the estimated number of days during each phase that the equipment was actually operated. In addition, estimated equipment work-cycle data were obtained for both pieces of equipment at several of the sites visited. It was found that estimates of work-cycle characteristics for the forklift trucks were reasonably consistent for the sites visited. However, the work-cycle characteristics for the compactors tended to vary, depending on specific work requirements. A summary of the average usage data, based on information collected during the field survey, is presented in Table 2-3. It should be noted that the estimated number of days during each construction phase that the equipment was actually operated has been presented in terms of percent of the total phase duration. It should also be noted that for several of the sites surveyed, two or more forklift trucks or manually guided compactors were present and operating at the same time. For those cases, the typical number of hours of operation for a single machine was multipled by the number of machines operating at the construction site and this number was then used in the computation of the average hours of operation for each equipment type, by site type and phase, as presented in Table 2-3*.

2.4 ESTIMATED USAGE DATA FOR NEW PIECES OF CONSTRUCTION EQUIPMENT

2.4.1 Data Limitations

Based on the data obtained from a construction site field survey, usage data were developed for forklifts trucks and manually guided compactors. Due to both time and budget constraints, the field survey was limited in terms of the number sites and site types examined and in terms of the geographical locations visited. As a result, equipment usage data developed from the field survey may not be applicable, on a national basis, to similar construction site

*This procedure employs the equivalent energy principle for determining noise exposure, i.e., the noise exposure resulting from the operation of two machines for a time period t is equivalent, on an energy basis, to the exposure produced by one machine operating for a time period of 2t. This procedure assumes that the noise intensities of the two machines are equal.

Table 2-3. SUMMARY OF AVERAGE USAGE DATA FOR MANUALLY GUIDED COMPACTORS AND FORKLIFT TRUCKS (Data Based on Construction Site Field Survey)

Site Type	Equipment Type	Number of Sites Used To Compute Averages	Average Hours of Operation and Percent of Use During Each Phase										Typical Work Cycle			
			Clearing		Excavation		Foundation		Erection		Finishing		Avg. Time, Min.	% of Work-Cycle Time at Various Power Settings		
			Hrs/Day	%	Hrs/Day	%	Hrs/Day	%	Hrs/Day	%	Hrs/Day	%		Idle	Avg.	Max.
Residential	Forklift Trucks	6	0.0	0.0	0.0	0.0	1.83	24.7	2.9	73.4	1.3	25.0	3.0	43.6	44.9	11.5
	Compactors	4	0.0	0.0	0.0	0.0	3.0	16.3	2.5	10.0	1.0	12.5	*	-	-	100**
Office/ Public Service	Forklift Trucks	9	0.0	0.0	0.0	0.0	1.3	2.2	2.8	91.1	0.0	0.0	4.0	57.5	32.5	10.0
	Compactors	6	0.0	0.0	0.0	0.0	3.2	7.5	1.7	7.5	0.7	1.7	*	-	-	100**
Industrial/ Commercial	Forklift Trucks	4	0.0	0.0	0.0	0.0	1.1	6.3	2.3	100	0.8	6.3	4.0	45.0	45.0	10.0
	Compactors	3	0.0	0.0	0.0	0.0	2.1	8.3	0.7	3.3	0.7	3.3	*	-	-	100**
Public Works	Forklift Trucks	0	-	-	-	-	-	-	-	-	-	-	-			
	Compactors	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	50.0	*	-	-	100**

* Varies depending on specific work requirements.

** Operates at single power/throttle setting.

types located in other areas of the United States. Therefore, in order to obtain a high degree of confidence in the assessment of noise impact resulting from the operation of construction forklift trucks and manually-guided compactors, it is recommended that a more representative sample of data be gathered, on a national basis, for each construction site type considered in EPA's noise impact model. Until such data are available, the limitations associated with the data presented in this section should be kept in mind.

2.4.2 Equipment Usage Data

With respect to the construction site model's input data requirements, equipment usage factors are one of the most critical input data elements. Other relevant equipment usage data include the average annual hours of machine use and the number of machines used in construction. Equipment usage factors for forklift trucks and manually guided compactors were developed from the data presented in Table 2-3 and from an estimated percentage of each site type employing each of the equipment types. These percentages were determined from the construction site field survey and are presented in Table 2-4.

Table 2-4. ESTIMATED PERCENTAGE OF EACH SITE TYPE EMPLOYING EACH NEW EQUIPMENT TYPE

Equipment Type	Site Type			
	Residential	Office/Public Service	Industrial/ Commercial	Public Works
Forklift Trucks	30	50	50	50*
Compactors (Manually Guided)	35	75	75	50*

*Assumed values based on work requirements associated with public works construction (see page 16 of Ref. 2).

Because both pieces of equipment were used at all of the industrial/commercial sites visited during the field survey, the equipment use percentages for this site type were assumed to be equal to those of the office/public service site types to obtain more realistic usage estimates. Also, since only one public works site type was observed during the field survey, representative use percentages for this site type could not be determined. However, it should be noted that due to the work requirements associated with public works construction (roads and utilities), it is reasonable to expect that both pieces of equipment are utilized to some degree at these site types (see Table A-1 in Ref. 1 and Table 5 in Ref. 2). Therefore, the following assumptions were made in order to determine the usage factors for both equipment types employed at public works sites:

- Both equipment types are used on one-half of all public works sites
- Forklift trucks are used 25 percent of the time during the erection and finishing phases
- Manually guided compactors are used 50 percent of the time during the erection and finishing phases.

As discussed in Section 2.2, the equipment usage factor is defined as the ratio of the equipment's total operating time during a given phase to the total phase duration. Based on the information presented in Table 2-3, total operating times for both equipment types were determined as a function of site type and construction phase. It was assumed that for public works sites, the hours of operation per day for forklifts and compactors are two and one hours, respectively. From the equipments' total operating times and from the site use percentages presented in Table 2-4, equipment usage factors were computed. A listing of these values is presented by site type and construction phase in Tables 2-5 through 2-8. A detailed description of the procedure used to determine the equipment usage factors is presented in Appendix A. It should be noted that, due to the limited number of construction sites visited during the field survey, it is assumed that equipment usage factors are functions of site type only and do not vary with respect to population density region.

Table 2-5. EQUIPMENT USAGE FACTORS FOR RESIDENTIAL CONSTRUCTION SITE TYPES

Equipment Type	Construction Phase				
	Clearing	Excavation	Foundation	Erection	Finishing
Forklift Trucks	0.0000	0.0000	0.0170	0.0798	0.0126
Manually Guided Compactors	0.0000	0.0000	0.0214	0.0109	0.0011

Table 2-6. EQUIPMENT USAGE FACTORS FOR OFFICE/PUBLIC SERVICE CONSTRUCTION SITE TYPES

Equipment Type	Construction Phase				
	Clearing	Excavation	Foundation	Erection	Finishing
Forklift Trucks	0.0000	0.0000	0.0008	0.1594	0.0000
Manually Guided Compactors	0.0000	0.0000	0.0225	0.0120	0.0011

Table 2-7. EQUIPMENT USAGE FACTORS FOR INDUSTRIAL/ COMMERCIAL SITE TYPES

Equipment Type	Construction Phase				
	Clearing	Excavation	Foundation	Erection	Finishing
Forklift Trucks	0.0000	0.0000	0.0051	0.1438	0.0032
Manually Guided Compactors	0.0000	0.0000	0.0179	0.0022	0.0022

Table 2-8. EQUIPMENT USAGE FACTORS FOR PUBLIC WORKS CONSTRUCTION SITE TYPES

Equipment Type	Construction Phase				
	Clearing	Excavation	Foundation	Erection	Finishing
Forklift Trucks	0.0000	0.0000	0.0000	0.0313	0.0313
Manually Guided Compactors	0.0000	0.0000	0.0000	0.0313	0.0313

In addition to equipment usage factors, two other relevant usage data elements should be discussed: 1) average annual hours of machine usage, and 2) number of machines used in construction. As mentioned in Section 2.2, if a machine's usage factors for each site type and phase and its average annual hours of use are known, the number of machines used in construction can be determined. Conversely, the machine's average annual hours of use can be determined by knowing its usage factors and the number used in construction. This relationship is defined mathematically by the following equation:

$$\sum_{i}\left\{N(i) \cdot [\sum_{l} H(k,l,i)]\right\} = N'(k) \cdot H'(k) \qquad (2)$$

where

- k, l and i = machine type, construction phase and site type, respectively
- H(k,l,i) = hours of use for machine type k, per phase l and site type i
- N(i) = total number of sites of type i
- N'(k) = total number of machines of type k used in construction
- H'(k) = average annual hours of usage for machine type k.

Using the above relationship, the estimated total number of fork-lift trucks and manually-guided compactors used in construction was determined. The average annual hours of machine use for each macnine were estimated from data presented in References 3, 4 and 5 and from information provided by local construction equipment sales, rental and repair companies. A summary listing of the estimated usage data for both pieces of equipment is presented in Table 2-9.

2.5 EQUIPMENT NOISE LEVEL DATA

Due to high speed wind conditions, equipment noise level measurements could not be performed during the field survey portion

Table 2-9. ESTIMATED USAGE DATA FOR FORKLIFTS AND COMPACTORS

Equipment Type	Usage Data Per Machine Type: Average Economic Lifetime, Hours	Typical Operational Lifetime, Years	Equipment Usage, Hours per Year	Total Hours of Annual Use, (N(i)·H(i)) Millions	Total Number of Machines Used in Construction
Forklift Trucks	7330[1/]	10[3/]	733	39.4	53,752
Manually Guided Compactors	3200[2/]	5[4/]	640	7.60	11,877

[1/] Reference 3, page 25 — construction type forklifts, pneumatic tired, gasoline engine.

[2/] Reference 3, page 6 — rammer and vibratory plate type, gasoline engine.

[3/] References 4 and 5 — based on typical operational lifetime of similar construction equipment types such as backhoes, mobile cranes, and wheel and crawler tractors.

[4/] Based on estimates provided by local construction equipment sales and repair companies.

of this study. However, using the publications collected for a previous EPA literature search study (Ref. 6) to obtain noise level data for several types of construction equipment, A-weighted noise measurements at 50 feet were obtained for the new equipment types. It is believed that the noise level data obtained from the literature are representative of the noise emitted from both pieces of equipment during normal operation. Using this data, average noise level values were determined. However, since the distribution of noise levels relative to the total population for each machine type is not known and since energy averaging tends to apply a greater relative weighting to the higher levels, arithmetic-averaging is believed to be more representative of each machine type. A listing of the average noise levels along with the range of levels and the number of measurements used to determine these averages are presented in Table 2-10.

Table 2-10. AVERAGE NOISE LEVELS FOR FORKLIFT TRUCKS AND MANUALLY GUIDED COMPACTORS

Equipment Type	A-Weighted Noise Level at 50 Feet, dBA		Number of Measurements Used
	Average	Range	
Forklift Trucks	83.4	79 - 86	7
Manually Guided Compactors	84.6	71 - 101	8

In general, a single piece of construction equipment does not operate during all phases of construction. For multiple phase operation, total operational time during each phase will vary as a function of site type. Each machine's contribution to the overall site noise level is determined by the following factors: 1) machine's average noise level, 2) duration of construction activity, and 3) number of hours of machine use during each construction phase. For each site type, the number of hours of machine use during each construction phase can be determined from the equipment's usage factor and the phase duration. Using equation (1) in Section 2.2 and the usage and noise level data presented in the preceding sections, the daily equivalent noise levels (the site noise level contributions), from the forklifts and compactors were determined for each of the four site types considered in the EPA's construction site noise impact model. Although the relative change in noise impact resulting from the addition of these equipment types to the impact model was not determined, the change in the site noise level at a reference distance of 50 feet for each site type was computed. This data and the daily equivalent noise levels for both pieces of equipment are presented by site type in Table 2-11. It should be noted that for each of the four site types, the site noise levels at 50 feet vary with respect to population density region category.* However, these variations are relatively small ranging from 0.2 dBA to 1.6 dBA. As a result of the site noise level variations, the change in site noise level resulting from the operation of forklift trucks and manually guided compactors was computed as the difference between the average site noise level (averaged over the five region categories) and the daily equivalent noise level contribution from the two pieces of equipment.

*These variations are due to usage factor differences for some equipment types.

Table 2-11. DAILY EQUIVALENT NOISE LEVELS ($L_{eq}(8)$), AND SITE NOISE LEVEL CHANGES

Equipment Type	A-Weighted Noise Levels at 50 Feet, dBA, By Construction Site Type							
	Residential		Office/Public Service		Industrial/Commercial		Public Works	
	Daily Equivalent Level	Change in Site Noise Level	Daily Equivalent Level	Change in Site Noise Level	Daily Equivalent Level	Change in Site Noise Level	Daily Equivalent Level	Change in Site Noise Level
Forklift Trucks Only	69.0	+0.8	70.9	+0.1	70.6	+0.1	64.7	0.0
Manually Guided Compactors Only	63.9	+0.3	64.5	0.0	61.8	0.0	65.9	+0.1
Forklift Trucks and Manually Guided Compactors	70.2	+1.1	71.8	+0.1	71.1	+0.1	68.4	+0.1

3. POPULATION DENSITY SHIFTS DURING THE NORMAL DAYTIME WORK PERIOD

3. POPULATION DENSITY SHIFTS DURING THE NORMAL DAYTIME WORK PERIOD

3.1 DESCRIPTION OF DATA REGUIREMENTS

The relationship between construction site activity and the population of the surrounding community is critical with respect to making a reasonable assessment of the total construction noise exposure and impact. To account for variations in population distributions, the EPA's construction site noise impact model distributes the total U. S. population into five SMSA* region categories - 1) high-density urban centers, 2) low-density urban centers, 3) urban fringe, 4) SMSA areas outside urban fringe and 5) outside SMSA.

The baseline population density values for each of the five region categories are shown below:

BASELINE POPULATION DENSITY VALUES**

	Region Category	Density (People/Sq. Mile)
1.	High-Density Urban Center	20,877
2.	Low-Density Urban Center	8,473
3.	Urban Fringe	2,286
4.	Outside Urban Fringe	1,623
5.	Outside SMSA	20

Because these baseline values were derived from 1970 census data regarding the residential distribution of the U. S. population, they do not reflect population density variations resulting from the

*A Standard Metropolitan Statistical Area (SMSA) is a county or group of contiguous counties which contain at least one city of 50,000 inhabitants or more, or "twin cities" with a combined population of at least 50,000.

**In this section, units for population density are people per square mile.

net transfer of people between the five region categories during the normal daytime work period.* However, according to Bureau of the Census publications regarding 1970 census data, (References 7 and 8), there appears to be a significant interchange of the working population between the geographic components of large metropolitan areas. Table 3-1 presents a summary of the total interchange of all workers by place of work and by place of residence within all SMSAs with total populations of 250,000 or more. From Table 3-1 it can be seen that approximately 30 percent of the workers who lived in SMSAs of 250,000 or more, but outside central cities, worked in these central cities. At the same time, however, about 18 percent of the workers living in the central cities commuted to jobs in the surrounding suburbs or areas outside the SMSA. It should be noted that over 50 percent of the 1970 SMSAs had populations of 250,000 or more and represented almost 90 percent of the total SMSA population.

TABLE 3-1. Workers Living in SMSA's of 250,000 or More by Place of Work: 1970 Census Data

Place of work	All workers living in specified SMSA's		Living in central cities		Living outside central cities	
	Number	Percent	Number	Percent	Number	Percent
Total	47,221,624	100.0	21,183,157	100.0	26,038,467	100.0
Working in SMSA of residence:						
Central cities	23,282,129	49.3	15,580,507	73.6	7,701,622	29.6
Outside central cities	18,153,121	38.4	3,102,806	14.6	15,050,315	57.8
Working outside SMSA of residence	2,424,157	5.1	660,496	3.1	1,763,661	6.8
Not reported	3,362,217	7.1	1,839,348	8.7	1,522,869	5.8

*The daytime work period is assumed to be typically between the hours of 8:00 a.m. and 5:00 p.m. corresponding to the time period when most construction activities occur.

To account for population transfer during the normal daytime work period, an earlier EPA study (Ref. 1) recommended an increase in the three highest population density region categories and a decrease in the other two. However, the adjustments were based on geographical regions located entirely within the SMSA boundary. Subsequently, the region categories were redefined (Ref. 2) to include the area outside the SMSAs, where a significant proportion of construction activity occurs, and to account for highly populated urbanized areas with large average population densities. Although it was assumed that there was sufficient similarity between some of the earlier (Ref. 1) and redefined (Ref. 2) region categories to allow the use of the earlier normal daytime work period population transfer adjustments, no data or justification were presented to support this assumption.

The following sections present a discussion of the results of an investigation to determine the average population density changes for the five region categories considered in EPA's construction noise impact model and describe the criteria and procedures used in obtaining these results.

3.2 STUDY METHODOLOGY AND CRITERIA

3.2.1 Comparison Between Urbanized Areas and SMSAs

The current baseline population-density regions are defined in terms of the distribution of U. S. population living in urbanized areas. However, available data pertaining to net population interchanges during the normal daytime work period are presented with respect to SMSA geographic components, i.e., central cities, areas outside the central cities but inside the SMSA, and areas outside the SMSA. Nevertheless, it is believed that with respect to population distribution, the SMSA components and the population density regions as defined in the noise impact model are very similar. This contention can be supported by comparing the population distributions inside and outside urbanized areas and SMSAs (see Table E in Reference 9) and recognizing that, in general, urbanized areas represent the densely settled core of the SMSAs. It should be noted that because the boundaries of SMSAs are determined by political lines, and those of urbanized areas by the pattern of urban land use, there are small segments of the latter which lie outside the SMSAs. However, the population within these segments was estimated to be about 1 percent of the total population living inside urbanized areas.

Also, it is reasonable to assume that higher concentrations of people within the urbanized areas and the SMSAs are found inside, rather than outside, the central cities. In fact, based on 1970 census data, 54 percent of the population inside urbanized areas lived in the central cities which comprised only 40 percent of the total urbanized land area.

3.2.2 Criteria for Categorizing Population Density Regions

In order to estimate the population interchange during the normal daytime work period, two assumptions were made to develop criteria which could be used to place each SMSA geographical component, including areas outside the SMSA, into one of the five population density regions. First, it was assumed that the high - and low-density urban centers were generally located within large SMSA central cities. Based on the same criteria used to define large SMSA central cities in an earlier EPA study (see Table IX, Reference 1), it was found that, with only a few exceptions, these cities had populations of approximately 400,000 or more. Using this criterion, SMSA central cities were grouped into one of two population density categories - 1) those greater than 8,500, and 2) those less than or equal to 8,500 but greater than 3,000. High- and low-density urban centers were assumed to be located in areas within central city categories 1 and 2, respectively. Second, it was assumed that the urban fringe and areas outside the urban fringe could also be categorized according to total population and average population density and that each of these regions had a total population of less than or equal to 400,000. The population density limits for the urban fringe and outside urban fringe were, respectively - 1) less than or equal to 3,000 but greater than 2,000, and 2) less than or equal to 2,000. Since areas outside the SMSA are determined by political boundaries, no specific population or population density criteria were required. A summary of the categorization criteria is presented in the following table:

CATEGORY	CRITERIA
High-Density Central Cities (High-Density Urban Centers)	Population >400,000 and density ρ >8,500
Low-Density Central Cities (Low-Density Urban Centers)	Population >400,000 and density 3,000 < ρ $\leq$ 8,500
Urban Fringe	Population $\leq$400,000 and density 2,000 <$\rho$$\leq$ 3,000
Outside Urban Fringe	Population $\leq$400,000 and density ρ $\leq$2,000
Outside SMSA	Determined from political boundaries

It should be noted that since no definitive population or land use characteristics criteria were available, some judgement was exercised in determining the criteria used to define population density regions and to categorize SMSA geographical components. However, the rationale used in developing this criteria is consistent with respect to the methodologies used in deriving similar data for other EPA studies and with respect to the baseline population density values currently used in the EPA construction site noise impact model.

3.3 COMPUTATIONAL PROCEDURE

The computational procedure employed to determine net population transfer of workers into and out of the SMSA geographical components during the normal daytime work period is lengthy and quite detailed. Therefore, only a general description of this procedure will be presented in this section. A more detailed description is presented in Appendix B. The following is a summary of the computational procedure:

- Central cities, as defined by the 1970 U. S. population census, contain population concentrations equivalent to the concept of urban centers.
- Populations and land areas of the geographical components within each of the SMSAs considered in this study were obtained from the <u>County and City Data Book</u> (Ref. 10).
- All population and land area within an SMSA but outside the central cities were divided into urban fringe and SMSA areas outside the urban fringe on a county basis.
- The distinction between the geographical components and their classification with respect to region category is made on the basis of absolute population and average population density in accordance with the criteria presented in Section 3.2.2.
- The transfer of workers into and out of the five SMSA region categories (on a central city and county basis) were determined from the U. S. census <u>Journey to Work</u> publication (Ref. 7).

- Data adjustments were made to account for:

  1. Workers leaving their SMSA of residence, but the geographical component in which they lived was not identified,

  2. Workers living within the SMSA but not reporting their living or working locations.

- Population density changes were determined from the residential population, the normal daytime work period population, and the total land area for each region category. Data is presented in terms of percent change in population density and is computed using the following equation:

$$PC = \frac{\overline{\Delta\rho}_{DW}}{\bar{\rho}_R} \cdot 100$$

where

PC = percent change in population density during normal daytime work period,

$\overline{\Delta\rho}_{DW}$ = average population density change resulting from population interchanges during normal daytime work period,

$\bar{\rho}_R$ = average residential population density

The average population densities were computed using the relationship:

$$\bar{\rho}_i = \frac{\sum_i \text{Population}}{\sum_i \text{Land Area}}$$

where

i represents a specific region category.

3.4 POPULATION DENSITY VARIATIONS DURING NORMAL DAYTIME WORK PERIOD

3.4.1 Population Density Changes by SMSA Region Category

Based on the criteria discussed in Section 3.2.2, six high-density and nine low-density central city SMSAs were selected for this analysis. Although the selection was influenced somewhat by the number of geographic components (central city plus surrounding counties), it is believed that with respect to location within the United States, and range of total SMSA residential population, the areas selected are representative of the larger SMSAs and reflect typical population interchange between the five SMSA regions. However, since the results developed from this analysis were derived from population data for SMSAs of 250,000 or more, it can only be assumed that they are applicable to the smaller SMSAs. The following is a listing of the sample SMSAs:

HIGH-DENSITY	LOW-DENSITY
Detroit	Houston
Baltimore	Milwaukee
San Francisco-Oakland*	San Antonia
Cleveland	Memphis
St. Louis	San Diego
Buffalo	Seattle-Everett**
	Atlanta
	San Jose
	Cincinati

* San Francisco considered as the urban center
** Seattle considered as the urban center

A summary of the sample population and land area data used to estimate percent change in population density for each of the four region categories inside the SMSA is presented in Table 3-2. It should be noted that the total normal working day population for the sample data is approximately 144,000 greater than the total residential population. This increase in population is a result of the net transfer of workers from outside to inside the sample SMSAs.

TABLE 3-2. Total Sample Population and Land Area Data Used to Determine Percent Change in Population Density by SMSA Region Category

SMSA Region Category	Residential Population	Normal Working Day Population	Land Area, Square Miles	Percent Change In Pop. Density[1]
High-Density Urban Center	4,971,407	5,636,882	440	13.4
Low-Density Urban Center	6,026,598	6,534,212	1892	8.4
Urban Fringe	3,128,597	3,116,368	697	-0.4
SMSA Area Outside Urban Frg.	12,627,619	11,610,413	35,223	-8.1

1/ Percent change in population density during normal daytime work period.

Note: Population and land area for each region category represent totals determined by summing over all sample SMSAs.

The estimated percent change in population density for the region outside the SMSAs was computed from the following: 1) the estimated normal daytime work period population density (as presented in Table 3-2) and total land area of the four region categories inside the SMSAs and 2) the total population and land area of the U. S.* Based on these data, the estimated percent change was determined to be approximately -5.7 relative to the residential population density. A discussion of the computational procedure used to obtain this estimate is presented in Appendix B.

3.4.2 Population Density Changes by Construction Site Type and by SMSA Region Category

The construction site noise impact model implicitly assumes that the population transfers and corresponding population density variations which occur during the normal daytime work period take place only in areas where there are office/public service and industrial/commercial construction activities and makes no population density adjustments with respect to areas with residential and public works sites. Also, based on an earlier EPA study (Ref. 2), it was assumed that as a result of worker transfer during the daytime period, there is a net population increase in the high- and low-density urban centers and in the urban fringe region and a net population decrease in the area outside the urban fringe and in the area outside the SMSA. Table 3-3 presents the population density values by site type and by SMSA region category currently used in the construction site noise impact model.

Based on data presented in the preceding sections, it is believed that the values shown in Table 3-3 should be revised to reflect the population density changes with respect to those areas, within each SMSA region category, where each type of construction activity is typically performed. To develop these revised values, several assumptions were made regarding the following: 1) the composition of each SMSA region category with respect to basic land use classifications,

*Based on U. S. population density and land area data presented in Table 8, Reference 2.

Table 3-3. POPULATION DENSITY VALUES BY SITE TYPE AND BY SMSA REGION CATEGORY, PEOPLE/SQ.MI.

Construction Site Type	SMSA Region Category				
	High-Density Urban Centers	Low-Density Urban Centers	Urban Fringe	SMSA Areas Outside The Urban Fringe	Outside SMSA
Residential	20,877	8,473	2,286	1,623	20
Office/Public Service	22,929	9,337	2,508	1,489	18
Industrial/ Commercial	22,929	9,337	2,508	1,489	18
Public Works	20,877	8,473	2,286	1,623	20

2) the distribution of total population and construction site types within the SMSA region categories and 3) the net transfer of population between land use categories. Based on these assumptions, which are listed in Appendix C, and data presented in Tables 3-1 and 3-2 and in Reference 9, revised population density values by site type and by SMSA region category were determined. These data are presented in Table 3-4. A discussion of the procedure used to determine the revised population density values is presented in Appendix C.

3.5 SUMMARY OF STUDY RESULTS

Based on the results of this investigation, the following general conclusions can be made:

1. With the exception of the outside urban fringe region category, the percent changes in the current baseline population density values used to account for normal daytime work period population transfer between the SMSA region categories do not agree with the results of this study.

2. The differences between the current baseline values and the values derived from this study for the percent change in population density for each SMSA region category are shown below:

SMSA REGION CATEGORY	PERCENT CHANGE IN POPULATION DENSITY DURING NORMAL DAYTIME WORK PERIOD		
	CURRENT	STUDY RESULT	ABSOLUTE DIFFERENCE
High-Density Urban Center	+ 9.8	+13.4	3.6
Low-Density Urban Center	+10.2	+ 8.4	1.8
Urban Fringe	+ 9.7	- 0.4	10.1
Outside Urban Fringe	- 8.3	- 8.1	0.2
Outside SMSA	-10.0	- 5.7	4.3

Table 3-4. REVISED POPULATION DENSITY VALUES BY SITE TYPE AND BY SMSA REGION CATEGORY, PEOPLE/SQ.MI.

Construction Site Type	SMSA Region Category				
	High-Density Urban Centers	Low-Density Urban Centers	Urban Fringe	SMSA Areas Outside the Urban Fringe	Outside SMSA
Residential	12,944	5,253	1,394	990	19
Office/Public Service	23,675	9,185	2,277	1,492	19
Industrial/ Commercial	23,675	9,185	2,277	1,492	19
Public Works	20,105	7,871	1,982	1,324	19

3. With the exception of the urban fringe region category, the current and study result values agree with respect to the relative direction of population transfer between SMSA region categories.

4. With respect to the urban fringe region category, it was found that for the high-density urban centers, the percent change in population density was -1.7; however, for the low-density urban centers, the percent change was +4.7 and, on the average (data for both urban center types combined), the percent change was almost negligible at -0.4.

5. With respect to the outside urban fringe region category, it was found that the percent change in population density for either the high-density or the low-density urban center SMSAs varied less than 15 percent of the average percent change based on the combined data for both urban center types.

3.6 RECOMMENDATIONS

Based on the conclusions made from the results of this study, the following is recommended:

1. Due to budget constraints, only a limited number of SMSA areas were examined; therefore, additional high- and low-density central city areas should be analyzed to support or to revise the conclusions made in this study.

2. The revised population density values by construction site type and by SMSA region category as determined from this study should be used to revise current baseline values. Also, consideration should be given to dividing the urban fringe region category into two separate regions, one for the high-density urban centers and the other for the low-density urban centers, since it appears from the study results that this region category has different population transfer characteristics depending on urban center type.

4. DURATION OF CONSTRUCTION SITE ACTIVITY

4. DURATION OF CONSTRUCTION SITE ACTIVITY

The total duration of construction activity assumed for each construction site type is a critical data element associated with the construction site noise impact model. The noise level weighting function used to represent the magnitude of noise impact is determined from the following equation:

$$W\left(L_{dn}^{a}\right) = \begin{cases} 0.05(L_{dn}^{a} - L_c) & \text{for } L_{dn}^{a} \geq L_c \\ 0 & \text{for } L_{dn}^{a} < L_c \end{cases} \qquad (4\text{-}1)$$

where L_{dn}^{a} is the annual day-night sound level, and L_c is the impact threshold criterion level. L_{dn}^{a} is a function of the assumed total duration (number 8-hour days) of construction site activity assigned to each of the four construction site types (see Section 3.4.2 in Reference 16).

Currently, the noise impact model assumes that the total duration of activity is a site-type dependent parameter only and, that the values used in the impact model for each site type are the same regardless of the geographical location within the United States. Additionally, it has been assumed that the value of the average population density surrounding a given site type has no influence on the duration of the construction activity.

In the following sections, a detailed evaluation of both of the above assumptions regarding the duration of construction site activity is presented.

4.1 DURATION OF CONSTRUCTION ACTIVITY BY SITE TYPE AND GEOGRAPHICAL LOCATION

4.1.1 Local Construction Activity

Data for local construction activity time periods (constructtion begin and end dates) were obtained from the Office of Research and Statistics (ORS) - Community Development Branch of Fairfax County, Virginia. ORS maintains statistical data identifying the duration of construction activity for three of the four site types considered in the construction site noise impact model: 1) residential, 2) office/public service, and 3) industrial/commercial. From the more than 45,000 records compiled by ORS, a random statistical sample consisting of 1,984 individual records was collected for detailed evaluation.

Data for the residential site types were divided into three structure-type categories: 1) single-family, 2) multi-family, and 3) town houses. These data were evaluated in two ways: 1) data for each structure-type category were analyzed individually, and 2) data for all three structure-type categories were combined and analyzed as a single data set.

Table 4-1 presents a summary listing of the statistical analyses of the average duration of construction activity as a function of site type for the three site types considered.

4.1.2 National Construction Activity

Data for national construction activity time periods were obtained from publications prepared by the U.S. Department of Commerce - Bureau of the Census.[11,12] These publications provided statistical data concerning the length of time from start of construction to completion for the following structure types:

TABLE 4-1 · ANALYSIS OF AVERAGE DURATION OF CONSTRUCTION SITE ACTIVITY BY SITE TYPE - LOCAL (FAIRFAX COUNTY, VA.) CONSTRUCTION ACTIVITY DATA

CONSTRUCTION SITE TYPE	NUMBER OF DATA POINTS	DURATION OF CONSTRUCTION SITE ACTIVITY, MONTHS	
		MEAN	Standard Deviation
Single-Family (Residential)	968	8.76	6.62
Multi-Family (Residential)	145	15.34	6.99
Town Houses (Residential)	508	12.70	8.05
All Residential Site Types (Single-Family, Multi-Family, Town Houses)	1,621	10.59	7.49
Office/Public Service	136	12.03	6.08
Industrial/ Commercial	227	9.22	5.08

* Single- and multi-family residential building projects,
* Non-residential building projects including industrial, office, commercial, and other non-residential construction (excluding highways, streets, and public utilities).

Single- and Multi-Family Residential Structures:

Tables 4-2 and 4-3 present annual data showing the average number of months from start to completion for new single- and multi-family buildings, respectively, for years 1971 to 1978. Table 4-2 presents these data with respect to geographical region within the U.S. while Table 4-3 shows average activity duration with respect to the number of units* in the building.

Non-Residential Building Projects:

Tables 4-4 and 4-5 present statistical data concerning construction activity durations for private non-residential building projects completed in 1976 and 1977. The data shown on both tables are categorized with respect to project cost (i.e., value of the project put in place). Table 4-4 lists the number of projects completed in a specific time period as a percentage of the total number of projects completed in a given cost category. These percentages are also shown cumulatively. For example, Table 4-4 shows that 17.4 percent of the projects costing between $100,00 and $250,000 were completed in the fourth month after the month of start; 55.5 percent were completed within four months after starting. Table 4-5 shows the average number of months from start of construction to completion for selected types of non-residential buildings. These non-residential building types include: 1) industrial, 2) office, 3) commercial, and 4) other non-residential (excluding highways, streets, and public utilities).

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* A housing unit is a single room or group of rooms intended for occupancy as separate living quarters by a family, by a group of unrelated persons living together, or by a person living alone.

TABLE 4-2 AVERAGE NUMBER OF MONTHS FROM START TO COMPLETION FOR NEW SINGLE-FAMILY HOUSES COMPLETED BY REGION (From Reference 11)

Year	United States	Geographic Region*			
		North-east	North Central	South	West
1971	4.8	5.9	5.2	4.4	4.4
1972	5.2	6.0	5.6	4.9	5.0
1973	6.0	6.5	6.0	5.8	5.9
1974	6.2	6.6	6.5	6.0	6.2
1975	6.1	6.3	6.6	5.8	6.1
1976	5.5	6.1	6.0	5.0	5.5
1977	5.7	5.8	5.8	5.4	6.0
1978	6.2	6.5	6.6	5.7	6.7
AVERAGE FOR ALL YEARS	5.7	6.2	6.0	5.4	5.7

* States contained in each geographic region are as follows:

NORTHEAST - Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, and Pennsylvania; NORTH CENTRAL - Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, and Kansas; SOUTH - Delaware, Maryland, District of Columbia, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida, Kentucky, Tennessee, Alabama, Mississippi, Arkansas, Louisiana, Oklahoma, and Texas; WEST - Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, Nevada, Washington, Oregon, California, Alaska, and Hawaii.

TABLE 4-3 AVERAGE NUMBER OF MONTHS FROM START TO COMPLETION FOR NEW MULTI-FAMILY BUILDINGS COMPLETED BY NUMBER OF UNITS IN THE BUILDING
(From Reference 11)

		Buildings with 5 units or more					
			Buildings with				
Year	Buildings with 2 to 4 units	Total	5 to 9 units	10 to 19 units	20 to 29 units	30 to 49 units	50 units or more
1971	5.9	8.6	7.7	8.4	8.6	9.1	12.7
1972	6.0	8.9	8.0	9.3	9.2	9.2	14.5
1973	7.2	10.1	9.6	10.1	10.8	10.5	15.1
1974	7.7	11.0	10.4	11.0	11.8	12.2	16.0
1975	7.4	12.0	11.7	11.4	12.2	13.7	18.3
1976	6.4	9.3	8.8	9.0	9.9	10.9	18.7
1977	6.4	8.8	8.5	8.7	8.8	10.3	16.9
1978	7.3	9.6	9.3	9.7	9.9	10.5	15.1
AVERAGE FOR ALL YEARS	6.8	9.8	9.3	9.7	10.2	10.8	15.9

TABLE 4-4. PRIVATE NONRESIDENTIAL BUILDING PROJECTS COMPLETED IN 1976 AND 1977 - PERCENT DISTRIBUTION OF PROJECTS BY NUMBER OF MONTHS FROM START OF CONSTRUCTION TO COMPLETION (From Reference 12)

(Components may not add to totals due to rounding)

Month work completed	Cost category and projects															
	$5,000,000 or more (443 projects)		$3,000,000 to $4,999,999 (365 projects)		$1,000,000 to $2,999,999 (1051 projects)		$500,000 to $999,999 (1067 projects)		$250,000 to $499,999 (1164 projects)		$100,000 to $249,999 (1604 projects)		$50,000 to $99,999 (1189 projects)		$25,000 to $49,999 (890 projects)	
	Monthly	Cumulative	Monthly	Cumulative	Monthly	Cumulative	Monthly	Cumulative	Monthly	Cumulative	Monthly	Cumulative	Monthly	Cumulative	Monthly	Cumulative
Same month as month of start...											0.8	0.8	1.5	1.5	5.1	5.1
1st month after month of start..			0.1	0.1	0.4	0.4	0.4	0.4	0.9	0.9	5.0	5.8	11.3	12.8	14.4	19.5
2nd month after month of start..			-	0.1	0.4	0.7	1.5	1.9	5.0	5.9	13.6	19.4	27.2	40.0	56.1	75.6
3rd month after month of start..	0.1	0.1	0.2	0.3	0.8	1.5	4.4	6.3	9.5	15.4	18.6	38.0	23.1	63.2	9.8	85.4
4th month after month of start..	-	0.1	-	0.3	2.7	4.2	8.9	15.2	12.6	28.0	17.4	55.5	11.6	74.8	6.9	92.3
5th month after month of start..	0.1	0.3	0.8	1.1	4.4	8.6	8.3	23.5	15.5	43.5	12.3	67.8	9.2	84.0	1.8	94.2
6th month after month of start..	0.2	0.5	0.1	1.2	8.0	16.6	11.5	35.0	11.9	55.4	10.7	78.5	5.6	89.6	1.5	95.7
7th month after month of start..	-	0.5	0.6	1.8	6.2	22.9	9.6	44.6	9.8	65.2	6.8	85.3	2.7	92.3	1.2	96.9
8th month after month of start..	0.3	0.8	1.9	3.8	8.8	31.6	9.0	53.6	8.1	73.3	3.8	89.1	1.4	93.7	0.5	97.3
9th month after month of start..	0.4	1.2	2.1	5.9	8.4	40.0	8.3	61.6	6.0	79.3	2.3	91.5	1.8	95.5	0.3	97.7
10th month after month of start..	1.0	2.2	5.0	10.9	6.8	46.8	5.9	67.6	3.4	82.7	2.1	93.6	1.1	96.6	0.2	97.9
11th month after month of start..	1.0	3.2	5.8	16.7	6.8	53.6	6.0	73.6	2.6	85.3	1.5	95.1	0.8	97.4	0.8	98.7
12th month after month of start..	2.7	5.9	10.2	26.9	5.1	58.7	5.6	79.1	3.1	88.4	1.2	96.3	0.4	97.8	0.2	98.9
13th month after month of start..	2.5	8.3	5.4	32.3	5.3	64.0	3.2	82.3	2.6	91.0	0.8	97.1	0.3	98.1	0.5	99.4
14th month after month of start..	2.8	11.1	3.2	35.5	5.2	69.3	2.8	85.1	2.2	93.2	0.6	97.7	0.2	98.2		
15th month after month of start..	5.3	16.4	4.2	39.7	4.1	73.4	3.2	88.3	1.4	94.6	0.2	97.9	0.4	98.6		
16th month after month of start..	3.4	19.8	4.4	44.1	3.0	76.4	2.4	90.7	1.3	95.9	0.2	98.1	0.1	98.8		
17th month after month of start..	4.2	24.0	3.6	47.7	4.7	81.1	1.8	92.5	0.8	96.7	0.2	98.3	0.3	99.0		
18th month after month of start..	3.0	26.9	4.6	52.3	2.2	83.3	1.3	93.8	0.3	97.0	0.2	98.5				
19th month after month of start..	5.6	32.6	7.7	60.0	1.7	85.0	1.0	94.8	0.7	97.8	0.1	98.6				
20th month after month of start..	5.5	38.0	1.9	61.9	3.1	88.1	0.6	95.3	0.1	97.9	0.4	99.0				
21st month after month of start..	3.2	41.2	3.9	65.9	1.3	89.3	0.7	96.0	0.3	98.2						
22nd month after month of start..	4.0	45.3	2.3	68.2	0.8	90.2	0.7	96.7	0.1	98.3						
23rd month after month of start..	2.7	48.0	3.1	71.2	1.0	91.2	0.3	97.0	0.2	98.5						
24th month after month of start..	5.2	53.2	3.6	74.8	0.7	91.8	0.3	97.3	0.3	98.8						
25th month after month of start..	3.0	56.2	2.8	77.6	0.4	92.3	0.3	97.6	0.1	98.8						
26th month after month of start..	3.8	60.1	3.9	81.5	0.9	93.2	0.2	97.8	0.1	98.9						
27th month after month of start..	4.4	64.4	1.8	83.3	1.1	94.2	0.2	98.0	0.6	99.5						
28th month after month of start..	2.5	66.9	2.6	85.9	1.1	95.3	0.4	98.4								
29th month after month of start..	3.5	70.4	1.0	86.9	0.7	96.0	0.4	98.8								
30th month after month of start..	2.2	72.6	3.1	90.0	0.2	96.2	-	98.8								
31st month after month of start..	2.8	75.4	0.6	90.6	0.1	96.2	0.1	98.9								
32nd month after month of start..	3.0	78.4	2.2	92.8	0.5	96.7	0.5	99.4								
33rd month after month of start..	3.5	81.9	0.9	93.7	0.3	97.0										
34th month after month of start..	1.6	83.5	0.5	94.2	0.9	97.9										
35th month after month of start..	2.6	86.1	1.2	95.4	0.1	98.0										
36th month after month of start..	2.0	88.2	0.2	95.6	0.3	98.3										
37th month after month of start..	2.1	90.3	-	95.6	0.5	98.7										
38th month after month of start..	1.3	91.6	0.7	96.3	-	98.7										
39th month after month of start..	1.1	92.7	0.4	96.7	0.1	98.8										
40th month after month of start..	1.0	93.6	1.1	97.8	0.2	99.0										
41st month after month of start..	1.6	95.3	0.2	98.0						100.0						100.0
42nd month after month of start..	2.0	97.3	1.3	99.3				100.0								
43rd month after month of start..	0.2	97.5										100.0				
44th month after month of start..	0.5	98.1												100.0		
45th month after month of start..	0.3	98.4														
46th month after month of start..	0.3	98.6		100.0												
47th month after month of start..	0.3	98.9														
48th month or more..............	1.1	100.0				100.0										

- Represents zero.

TABLE 4-5 PRIVATE NONRESIDENTIAL BUILDING PROJECTS COMPLETED IN 1976 AND 1977 - AVERAGE NUMBER OF MONTHS FROM START OF CONSTRUCTION TO COMPLETION FOR SELECTED TYPES OF CONSTRUCTION (From Reference 12)

Value of project	Construction Types: All types	Industrial	Office buildings	Other commercial	Other nonresidential
$5,000,000 or more	24.9	23.2	25.7	21.2	28.4
$3,000,000 to $4,999,999	19.3	16.8	18.1	18.9	22.2
$1,000,000 to $2,999,999	12.9	12.0	14.8	11.2	15.0
$500,000 to $999,999	9.4	8.0	10.5	8.4	11.5
$250,000 to 499,999	7.3	6.2	7.7	6.6	9.2
$100,000 to $249,999	5.1	4.8	5.4	4.5	7.1
$50,000 to $99,999	4.0	3.7	3.7	3.5	6.7
$25,000 to $49,999	2.9	2.7	2.6	2.7	4.6
AVERAGE FOR ALL PROJECT VALUES	10.7	9.7	11.1	9.6	13.1

Note: Average number of months assumes projects completed in month started took full month; projects completed in first month following month of start took 1.5 months; projects completed in second month following month of start took 2.5 months; projects completed in third month following month of start took 3.0 months; projects completed in fourth month following month of start took 4.0 months; etc.

4.2 DURATION OF CONSTRUCTION SITE ACTIVITY BY SITE TYPE AND SURROUNDING POPULATION DENSITY VALUE

The construction site noise impact model assumes that the duration of construction site activity is independent of the surrounding population density value. That is, for a given construction site type, the length of time from start to completion of the project is the same in all five SMSA region categories considered in the noise impact model. On a national basis, there is currently no data available which can be used to support or to refute the assumption that the average duration of construction site activity is independent of the surrounding population density value. However, data for local (Fairfax County, Va.) construction projects were obtained from the Office of Research and Statistics (ORS) - Community Development Branch of Fairfax County, Virginia.

From a listing of more than 45,000 records concerning construction projects throughout Fairfax County, a random statistical sample consisting of 1,984 individual records was collected. For each individual record, the following items were recorded: 1) type of construction project, 2) length of time from start to completion of the project, and 3) location of the project identified by census tract number. From census data presented in Fairfax County publications,[13,14,15] census tract population density values* for 1,046 of the 1,984 individual construction project records were computed.

Based on the data described above, the mean census tract population density value, and the relationship between census tract population density and duration of construction activity were evaluated for the following construction site types: 1) residential, 2) office/

*Average population density values were computed from the total poplation and the total occupied land area specified for each census tract number. These data were presented in References 13,14, and 15.

public service, and 3) industrial/commercial. Additionally, data for the residential site types were divided into three structure-type categories (single-family, multi-family, and town houses) and evaluated as separate data set. Table 4-6 presents a summary listing of the results of the statistical analyses of the mean census tract population density associated with each construction site type. Table 4-7 and Figures 4-1 through 4-6 present the results of the linear regression analyses of the relationships between duration of construction site activity and census tract population density. APPENDIX D presents a complete listing of the data used to compute the mean census tract population density values shown on Table 4-6, and to derive the relationships between duration of construction site activity and census tract population density shown on Table 4-7.

4.3 EVALUATION OF STUDY RESULTS

4.3.1 Duration of Construction Activity by Site Type and Geographical Location

Single- and Multi-Family Residential Structures:

Table 4-8 presents a summary listing of annual data showing the percentage distribution of the number of residential building project starts by geographical location and structure type (i.e., structures with 1 unit, 2-4 units, or 5 units or more) over the period of from 1971 to 1978. Table 4-8 is derived from statistical data presented on Table 7 in Reference 11. Based on the information listed in Tables 4-2, 4-3, and 4-8, a weighted-average construction activity duration time period was determined for residential site types. The weighted-average duration accounts for the differences in the average construction activity duration and the relative number of building projects associated with each structure type category. The weighted-average construction activity durations, by geographical region, are shown below:

TABLE 4-6 ANALYSIS OF AVERAGE CENSUS TRACT POPULATION DENSITY AS A FUNCTION OF CONSTRUCTION SITE TYPE - COMPUTED FROM LOCAL (FAIRFAX COUNTY, VA.) DATA

CONSTRUCTION SITE TYPE	NUMBER OF DATA POINTS	CENSUS TRACT POPULATION DENSITY, PEOPLE/SQ. MI.	
		MEAN	Standard Deviation
Single-Family (Residential)	669	1,580	1,800
Multi-Family (Residential)	50	9,910	8,590
Town Houses (Residential)	242	3,920	3,620
All Residential Site Types (Single-Family, Multi-Family, and Town Houses)	961	2,600	3,640
Office/Public Service	34	2,690	2,770
Industrial/ Commercial	51	2,570	2,720

TABLE 4-7 ANALYSIS OF THE RELATIONSHIPS BETWEEN DURATION OF CONSTRUCTION SITE ACTIVITY AND CENSUS TRACT POPULATION DENSITY - RELATIONSHIPS DERIVED FROM LOCAL (FAIRFAX COUNTY, VA.) DATA

	BEST FIT LINEAR RELATIONSHIP: DURATION = a + b· (Population Density)		
CONSTRUCTION SITE TYPE	a	b	Correlation Coefficient
Single-Family (Residential)	6.671	4.0×10^{-5}	0.0268
Multi-Family (Residential)	11.433	-11.0×10^{-5}	-0.3390
Town House (Residential)	9.124	-9.0×10^{-5}	-0.1107
All Residential (Single-Family, Multi-Family, and Town Houses)	7.131	11.0×10^{-5}	0.1313
Office/Public Services	8.643	7.0×10^{-5}	0.0513
Industrial/ Commercial	7.128	22.0×10^{-5}	0.2241

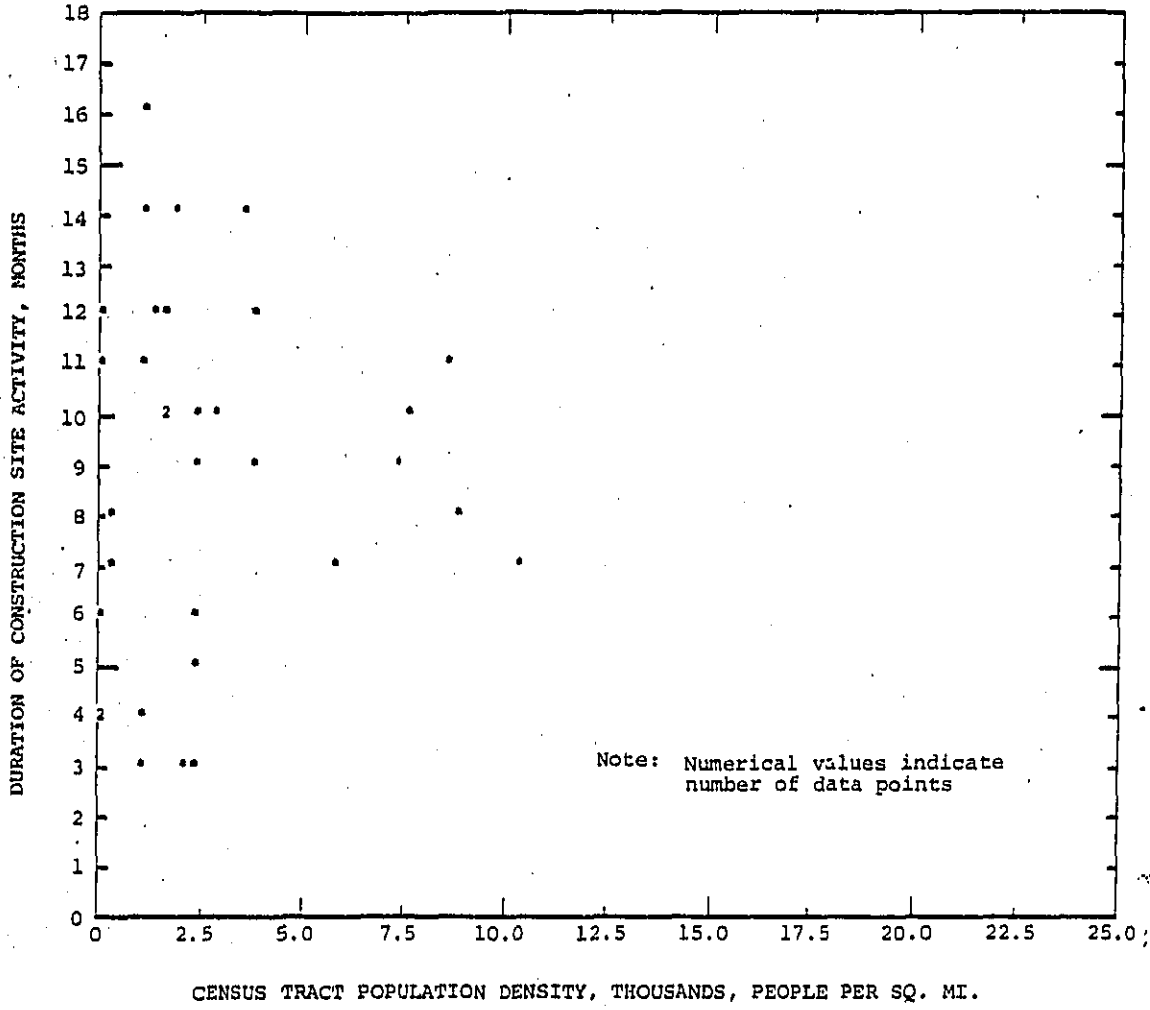

FIGURE 4-1 RELATIONSHIP BETWEEN DURATION OF CONSTRUCTION SITE ACTIVITY AND CENSUS TRACT POPULATION DENSITY; OFFICE/PUBLIC SERVICE SITE TYPES

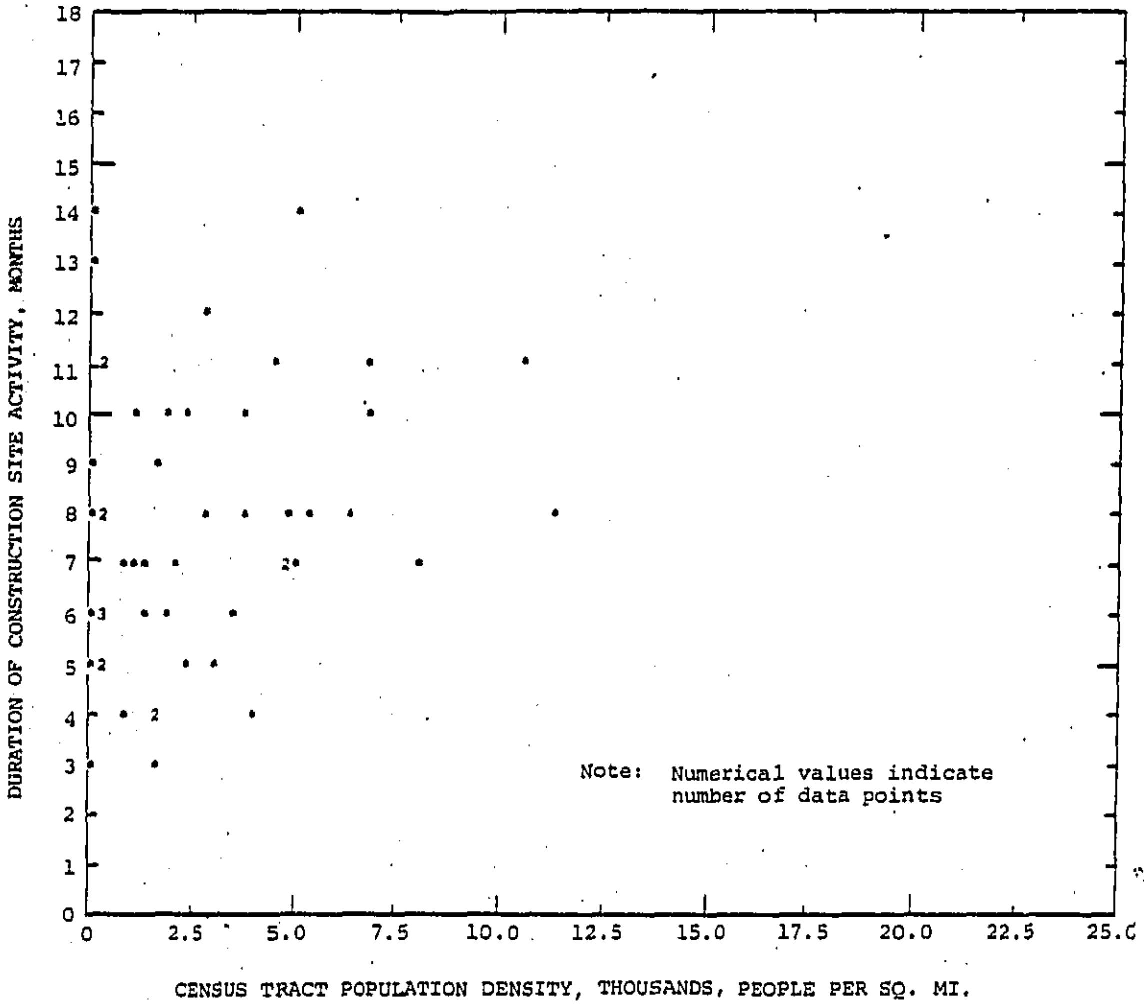

FIGURE 4-2 RELATIONSHIP BETWEEN DURATION OF CONSTRUCTION SITE ACTIVITY AND CENSUS TRACT POPULATION DENSITY; INDUSTRIAL/COMMERCIAL SITE TYPES

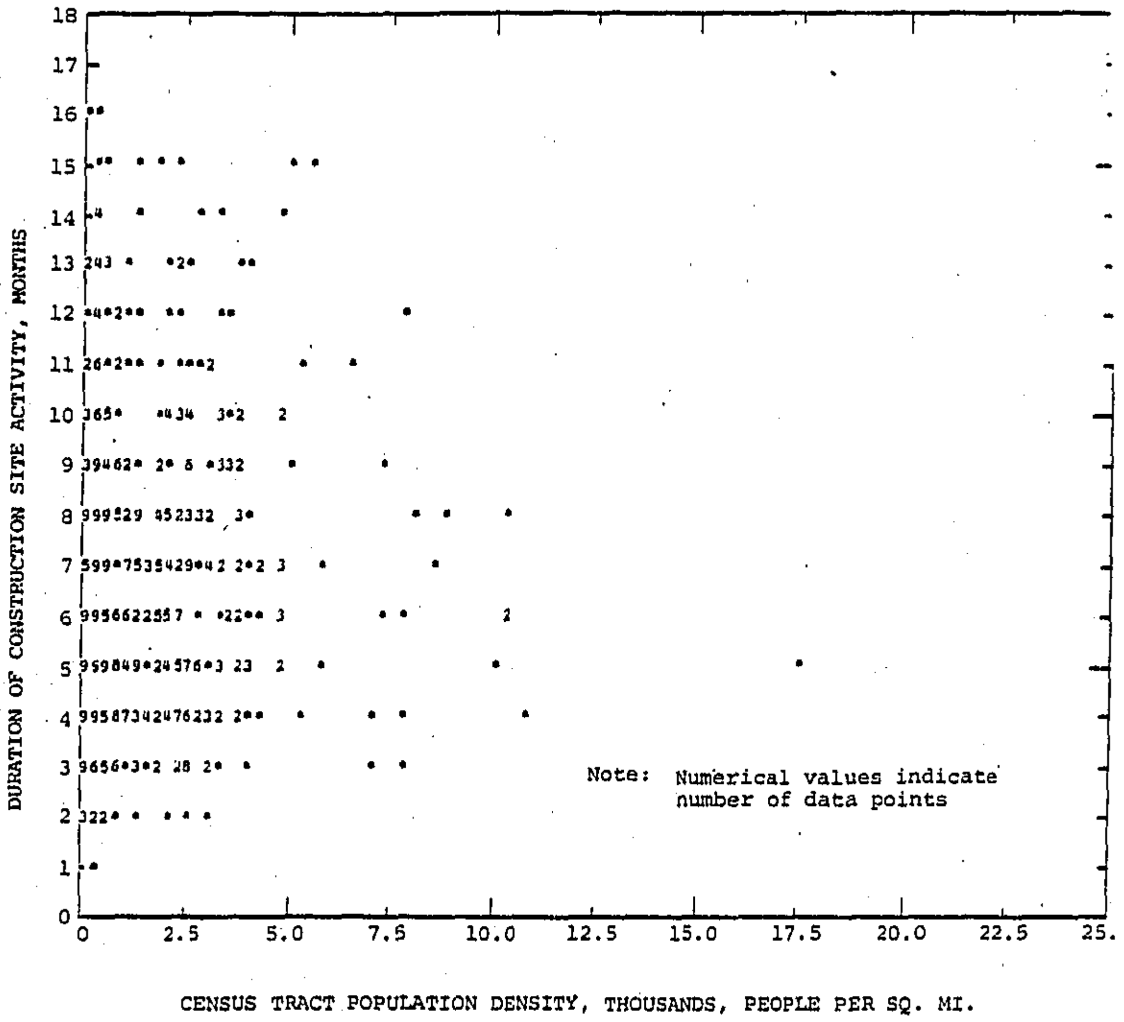

FIGURE 4-3 RELATIONSHIP BETWEEN DURATION OF CONSTRUCTION SITE ACTIVITY AND CENSUS TRACT POPULATION DENSITY; SINGLE-FAMILY (RESIDENTIAL) SITE TYPES

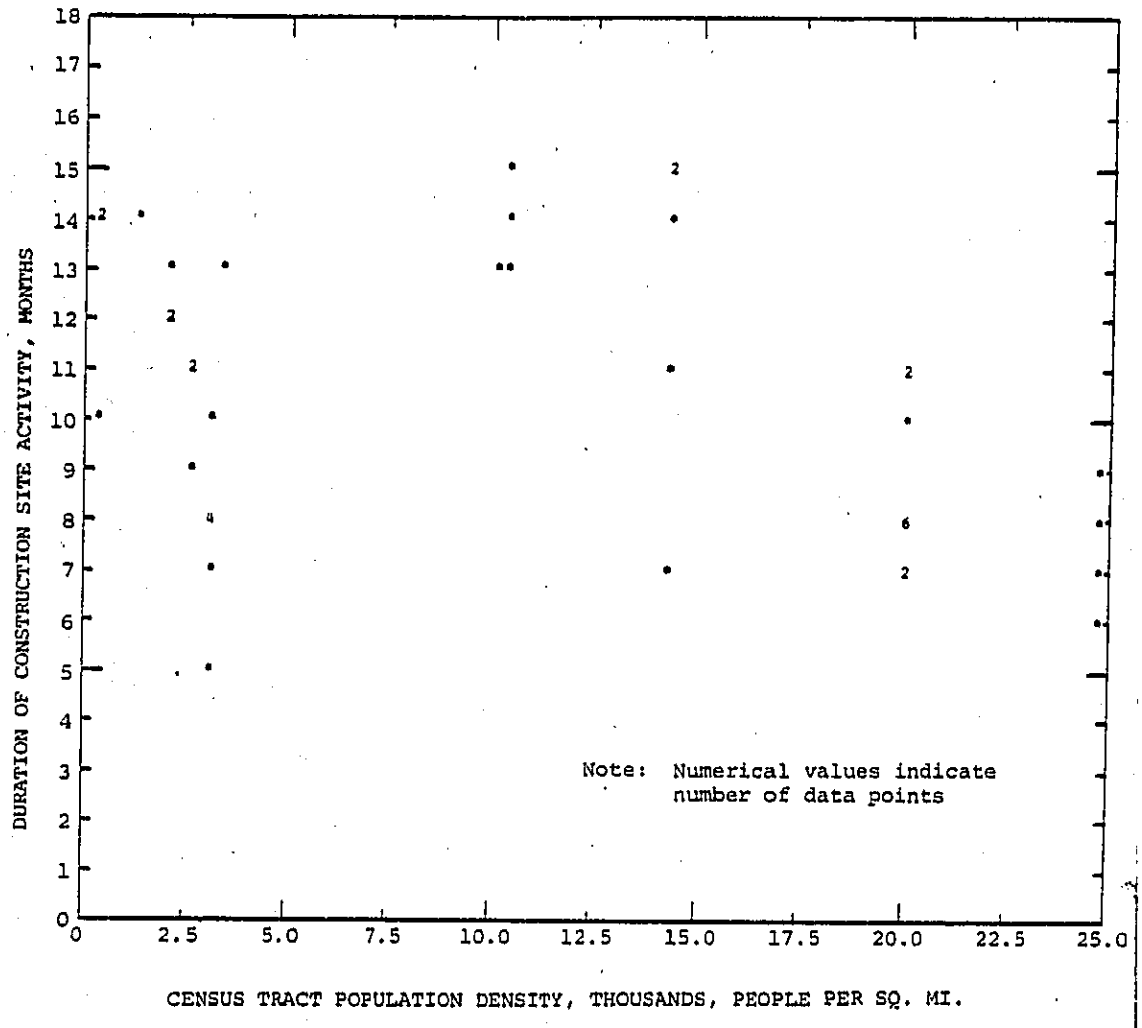

FIGURE 4-4 RELATIONSHIP BETWEEN DURATION OF CONSTRUCTION SITE ACTIVITY AND CENSUS TRACT POPULATION DENSITY; MULTI-FAMILY (RESIDENTIAL) SITE TYPES

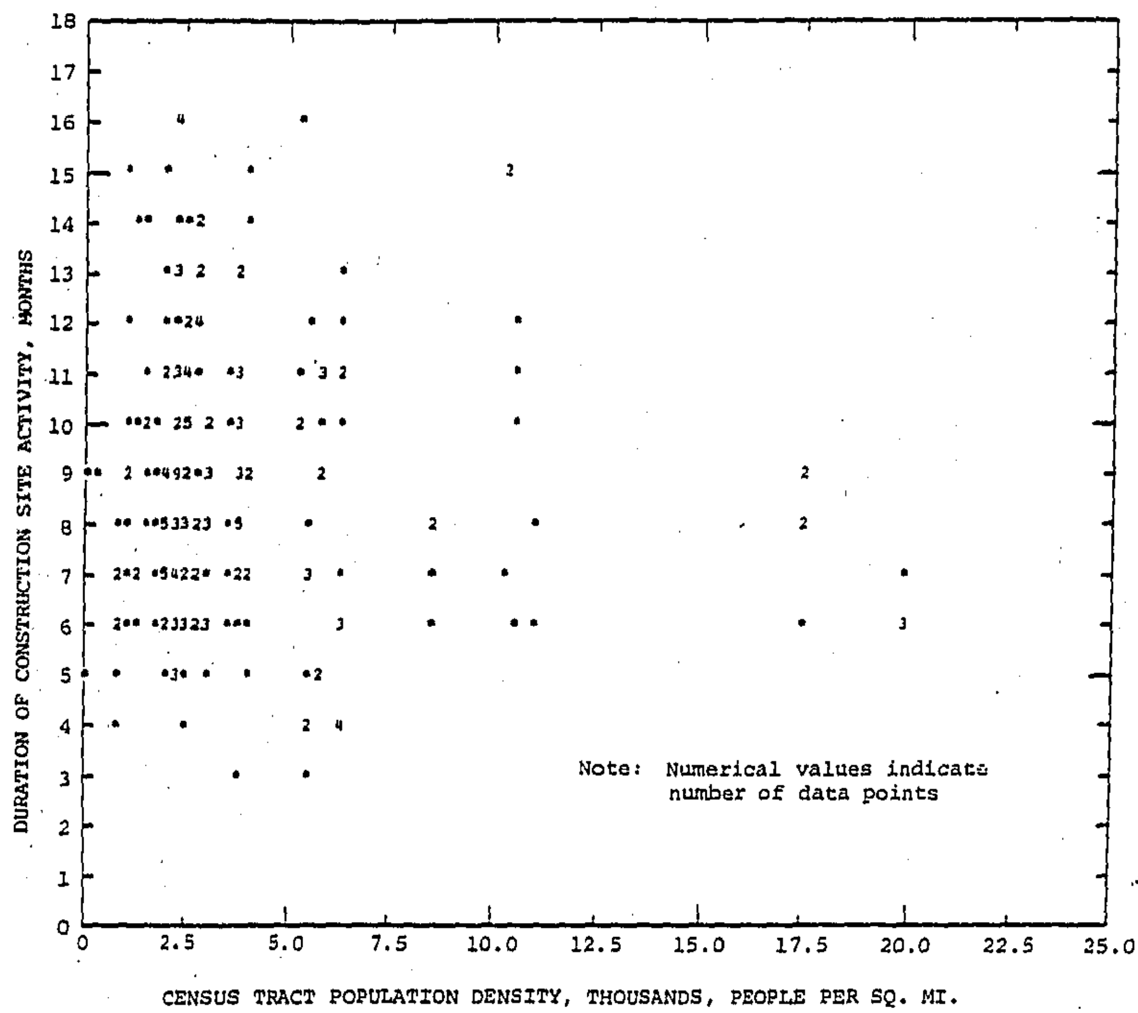

FIGURE 4-5 RELATIONSHIP BETWEEN DURATION OF CONSTRUCTION SITE ACTIVITY AND CENSUS TRACT POPULATION DENSITY; TOWN HOUSE (RESIDENTIAL) SITE TYPES

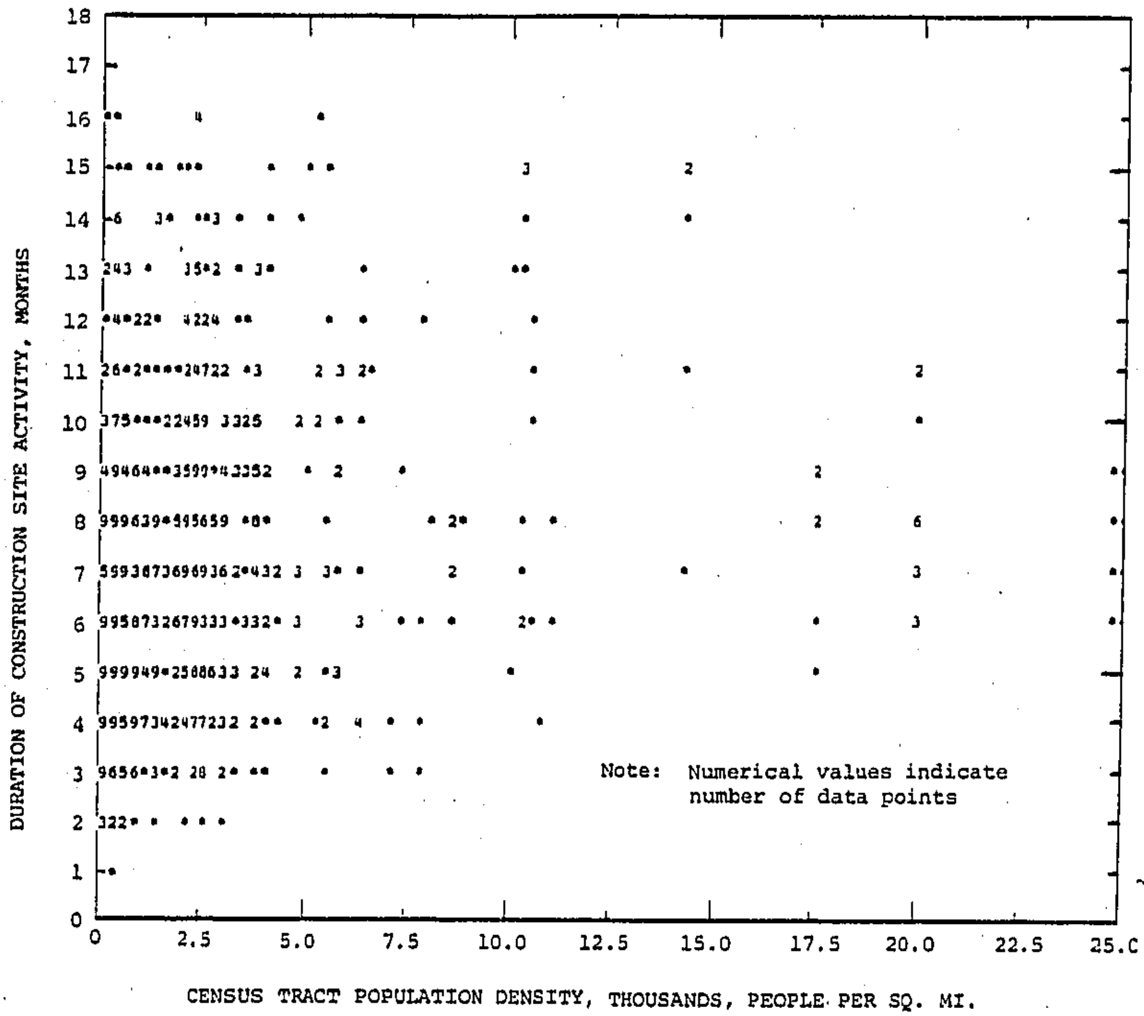

FIGURE 4-6 RELATIONSHIP BETWEEN DURATION OF CONSTRUCTION SITE ACTIVITY AND CENSUS TRACT POPULATION DENSITY; RESIDENTIAL (SINGLE-FAMILY, MULTI-FAMILY, AND TOWN HOUSE) SITE TYPES

TABLE 4-8 PERCENTAGE DISTRIBUTION OF THE NUMBER OF RESIDENTIAL BUILDING PROJECT STARTS BY GEOGRAPHICAL LOCATION AND STRUCTURE TYPE (From Reference 11)

(Components may not sum to 100 percent due to rounding)

Year	United States			Northeast			North Central			South			West		
	Structures with --			Structures with --			Structures with --			Structures with --			Structures with --		
	1 unit	2 - 4 units	5 units or more	1 unit	2 - 4 units	5 units or more	1 unit	2 - 4 units	5 units or more	1 unit	2 - 4 units	5 units or more	1 unit	2 - 4 units	5 units or more
1971	56.1	5.8	38.1	54.9	6.1	39.0	54.8	5.3	39.9	60.5	4.4	35.1	49.7	9.1	41.2
1972	55.6	6.0	38.5	51.6	5.8	42.6	57.8	5.6	36.6	57.9	4.2	37.9	51.6	9.7	38.7
1973	55.4	5.8	38.9	56.0	6.1	37.9	61.1	5.2	33.6	53.2	4.1	42.7	53.6	9.6	36.8
1974	66.4	5.1	28.6	65.0	4.9	30.1	71.0	4.7	24.3	66.4	4.0	29.7	61.8	8.4	29.8
1975	76.9	5.5	17.6	75.1	5.4	19.5	75.5	5.8	18.7	82.8	3.6	13.6	69.8	8.4	21.8
1976	75.6	5.7	18.8	75.2	4.7	20.1	73.5	5.8	20.8	81.5	3.3	15.1	69.2	9.3	21.5
1977	73.0	6.1	20.8	77.2	5.0	17.8	72.5	6.2	21.3	75.1	4.1	20.8	68.8	9.5	21.7
1978	70.9	6.2	22.9	73.5	5.0	21.5	72.1	6.2	21.7	73.3	4.2	22.5	65.1	9.2	25.7
AVERAGE FOR ALL YEARS	66.2	5.8	28.0	66.1	5.4	28.6	67.3	5.6	27.1	68.8	4.0	27.2	61.2	9.2	29.7

Weighted-Average Construction Activity Duration, Months

Geographical Region				
United States	North-east	North Central	South	West
6.9	7.3	7.1	6.7	7.0

Non-Residential Building Projects:

Table 4-9 presents a summary listing of annual data showing the percentage distribution of the number of private industrial, commercial, office, and public service building project starts in the U.S. for time periods 1976 and 1977. Table 4-9 is derived from statistical data presented on Table C-2 in Reference 22. A distribution of the number of building projects by geographical region was not provided. Therefore, the data presented on Table 4-9 is applicable only on a national basis. From the data presented on Tables 4-5 and 4-9, weighted-average construction activity duration time periods were determined for the industrial/commercial and office/public service building project types (i.e., the industrial plus commercial building projects, and office plus public service building projects). The weighted-average durations, by building project type, are shown below:

Weighted-Average Construction Activity Duration, Months

Industrial/Commercial	Office/Public Service
9.6	12.9

4.3.2 Duration of Construction Site Activity by Site Type and Surrounding Population Density

Based on local construction activity data and census tract population density values, the relationship between average population density and duration of construction activity shows a rather poor correlation. This poor correlation has been shown (Table 4-7) to be independent of construction site type. However, it should be noted

TABLE 4-9 PERCENTAGE DISTRIBUTION OF THE NUMBER OF PRIVATE INDUSTRIAL, COMMERCIAL, OFFICE, AND PUBLIC SERVICE BUILDING PROJECT STARTS (From Reference 22)

(Components may not sum to 100 percent due to rounding)

	BUILDING PROJECT TYPE			
Year	Industrial	Commercial*	Office	Public Service**
1976	9.9	24.1	7.3	58.7
1977	10.6	24.4	7.5	57.5
AVERAGE	10.3	24.3	7.4	58.1

* Includes: service stations, repair garages, stores and other mercantile buildings, and amusement buildings.

** Includes: religious buildings, educational buildings, hospitals and other institutional buildings, and other non-residential buildings.

that data used to establish the relationships between average population density and construction activity duration were obtained, most likely, from a single SMSA region whose characteristics should closely resemble those of the urban fringe. This conclusion is supported by mean population density data presented on Table 4-6. As can be seen from Table 4-6, the mean population density values for the three construction site types considered in the local data analyses are not significantly different from that assumed for the urban fringe SMSA region (i.e., 2,286 people/sq. mile).

4.3.3 Comparison of Study Results With Data Currently Used in the Construction Site Impact Model

The construction activity time periods presented in the preceding sections have been concerned with the length of time from start to completion of construction projects. These time periods are derived from data associated with the issuance of building permits, and do not represent actual construction activity time periods, i.e., the cumulative time period when construction activity is occurring. During the time from start to completion, there is some "down-time" which is comprised of: 1) weekends, 2) holidays, and 3) days when inclement weather will not permit any construction activity. It is assumed that over any construction activity time period, approximately 54 percent of this time period is down-time. The percentage distribution of this down-time is assumed to be:

1) weekends - 28 percent
2) holidays - 3 percent
3) days due to inclement weather* - 23 percent

Based on the above assumptions and the weighted-average construction activity durations presented in Section 4.3.1, the number of 8-hour

* Represents one-third of the available 8-hour workdays when construction activity could occur.

days of actual construction activity has been determined, on a national basis, for three of the four site types considered in the construction site noise impact model: 1) residential, 2) office/public service, and 3) industrial/commercial. A comparison of these data and the data currently used in the impact model is shown below:

SITE TYPE	NUMBER OF 8-HOUR DAYS OF CONSTRUCTION ACTIVITY: CURRENT	STUDY RESULT	ABSOLUTE DIFFERENCE
Residential	60	97	37
Industrial/ Commercial	170	134	36
Office/Public Service	170	181	11

4.3.4 Summary of Study Results

An investigation was performed to evaluate the duration of construction activity for residential, office/public service, and industrial/commercial site types, and to determine the influence of geographical location within the U.S. and surrounding population density on the average construction activity duration time periods. Based on the results of this investigation, the following have been concluded:

1. For residential site types, the weighted-average construction activity duration time period (i.e., length of time from start to completion of the building project) does not vary significantly with respect to geographical location within the U.S. For office/public service and industrial/commercial site types, no data were available to determine the relationship between activity duration and geographical location.

2. Based on local construction activity data and census tract population density values, the relationship between average population density and duration of construction activity, for all site types considered, has a low degree of correlation.

3. Compared with the data currently used in the construction site noise impact model, the study results show that the average (on a national basis) number of 8-hour days of construction activity for the residential and industrial/commercial site types may be underestimated by approximately 38 percent and 27 percent, respectively. For the office/public service site types, the construction activity duration may be overestimated by approximately 6 percent. Some uncertainty in these comparisons exists due to the assumption made regarding the percentage of construction activity "down-time" used in determining the average number of 8-hour days of construction activity. Down-time is defined as the percentage of the construction project start-to-completion time period during which no construction activity occurs.

5. NOISE-REDUCTION VALUES FOR VARIOUS BUILDING-STRUCTURE TYPES

5. NOISE-REDUCTION VALUES FOR VARIOUS BUILDING-STRUCTURE TYPES

The impact criteria used to assess construction site noise impact are based on indoor activity interference and annoyance noise-effects relationships presented in the EPA "Levels Document". The indoor noise impact threshold level is 45 L_{dn}.

Impact calculations associated with office/public service and industrial/commercial construction in high- and low-density urban center population density region categories are performed relative to an L_{dn} outdoor threshold of 65 dB. For all other construction site type and population density region category combinations, the impact calculations are performed relative to an outdoor L_{dn} threshold level of 55 dB. These impact threshold levels are based on two assumptions: 1) in the high- and low-density urban centers, building structures near office/public service and industrial/commercial construction sites provide, on the average, a 20 dB reduction between exterior and interior noise levels, 2) the noise reduction between exterior and interior noise levels in all other cases is 10 dB. The implications of these two assumptions are: 1) building noise-reduction values are primarily a function of the building structure type, i.e., the building's physical characteristics, 2) building structures which afford 20 dB of noise reduction are typically large office/public service and high rise apartment and commercial building types with heavy wall construction, and double-glazed windows, and 3) building structures which afford 10 dB of noise reduction are typically light-weight, single- and multi-family dwellings with light wall construction, and single-pane glass windows.

The following sections present a detailed evaluation of available data concerning "typical" or average noise-reduction values for the following building-structure types:

1. single-family residential
2. office/public service
3. commercial/apartment high rise

The evaluation is based on a review of earlier and more resent publications concerning outdoor-indoor noise level reduction investigations. Building noise-reduction (i.e., the difference between exterior and interior noise levels), rather than sound tranmission loss, is evaluated since it has been observed that building noise-reduction values measured in the field generally fall well below those that would be predicted from the transmission loss properties of basic wall or roof structures.

5.1 SINGLE-FAMILY RESIDENTIAL STRUCTURES

5.1.1 Early Investigations Of Building Noise-Reduction

Most of the earlier investigations related to the noise-reduction* characteristics of various types of buildings were concerned primarily with residential dwellings (single-family houses) exposed to aircraft noise sources.[17,18,19] The noise reductions were generally expressed in terms of two noise descriptors: 1) perceived-noise levels (PNL) and, 2) A-weighted sound levels. Evaluation of data presented in References 17, 18 and 19 have shown that the average differences between noise reduction values expressed in terms of dBA and PNdB (i.e., $NR_{dBA} - NR_{PNdB}$) are on the order of one-half of a dB. However, this difference was determined from propeller and turbine powered aircraft noise sources and, may not be applicable to other noise sources.

* Building noise reduction (NR) is defined as the difference between the maximum sound levels observed outside a building and inside a building during discrete or continuous noise events.

Bishop[17] (1965) reported the results of a study to determine typical aircraft noise reduction values for furnished living rooms and bedrooms in residential buildings. Table 5-1 presents a summary of the results reported. The data shown on Table 5-1 are given in terms of PNdB and dBA, where the dBA values are computed using the approximation: dBA $\approx$ PNdB + 0.5 dB. Young[18] (1970) reported the results of an investigation to determine the aircraft noise attenuation characteristics of two furnished houses - a wood-sided frame house and a brick-veneered frame house. A four-engine propeller-driven aircraft and a four-engine turbofan aircraft were used as noise sources. All indoor measurements were obtained with the windows closed. The building noise-reduction data were expressed in terms of thirty-six physical noise measures. Table 5-2 presents a summary listing of the results reported in Reference 18, in terms of PNL and A-weighted sound level only.

In October 1971, the Society of Automotive Engineering, Inc. published an Aerospace Information Report (AIR) describing the results of several house noise-reduction investigations conducted in five locations* in the U.S.[19] The purpose of this document (AIR 1080) was to present actual measurement data showing the noise reduction of aircraft flyover noise from the outside to the inside of houses located in various climates and with various window configurations (i.e., open and closed). Average house noise-reduction values were grouped in accordance with the following four climate/window configuration categories:

1. Warm climate / windows open,
2. Warm climate / windows closed,
3. Cold climate / windows open,
4. Cold climate / windows closed.

---

* These locations included: 1) New York, 2) Boston, 3) Miami, 4) Los Angeles, and 5) Wallops Station, Virginia.

TABLE 5-1 REDUCTION OF AIRCRAFT NOISE OBSERVED FOR LIVING ROOMS AND BEDROOMS IN SINGLE-FAMILY RESIDENTIAL STRUCTURES (From Reference 17)

TYPE OF NOISE SIGNAL	ROOM TYPE	NUMBER OF MEASUREMENTS	MEAN NOISE REDUCTIONS PNdB	dBA
Takeoff	Living Room	39	20.9	21.4
Takeoff	Bedroom	39	24.1	24.6
Approach	Living Room	46	22.1	22.6
Approach	Bedroom	46	23.8	24.3
		AVERAGE	22.7	23.2

TABLE 5-2 REDUCTION OF AIRCRAFT FLYOVER NOISE OBSERVED FOR VARIOUS ROOMS IN SINGLE-FAMILY RESIDENTIAL STRUCTURES (From Reference 18)

HOUSE TYPE	ROOM TYPE	NUMBER OF MEASUREMENTS	MEAN NOISE REDUCTION* PNdB	MEAN NOISE REDUCTION* dBA
Brick-Veneer Frame	Dining Room	4	23.1	23.4
	Living Room	4	21.2	21.8
	Bedroom No.1	4	27.5	27.5
	Bedroom No.2	4	25.9	26.0
Wood-Sided Frame	Dining Room	4	22.8	21.3
	Living Room	4	21.2	19.7
	Bedroom No.1	4	25.3	24.6
	Bedroom No.2	4	18.1	18.0
		AVERAGE FOR BOTH HOUSE TYPES	23.1	22.8

*Average of the noise-reduction values computed using three data analysis techniques:

1. Outdoor noise intensity minus indoor intensity at the time when the outdoor noise was maximum,
2. Outdoor noise intensity minus indoor noise intensity at the time when the indoor noise was maximum,
3. Maximum outdoor noise intensity minus the maximum indoor noise intensity.

Table 5-3 and Table 5-4 present the average house noise-reduction values in terms of octave-band (from 63 Hz to 4000 Hz) sound pressure level and in terms of overall A-weighted sound level, respectively, for each of the four climate/window configurations.

5.1.2 Recent Investigations of Building Noise Reduction

Data from a recent publication [20] by Sutherland (1978) has augmented the available outdoor-indoor noise-reduction data for single-family (detached dwellings) residential structures. These recent data include noise-reduction measurements for both aircraft and highway traffic noise sources and, are given in terms of the difference between outdoor and indoor A-weighted sound levels with windows open and windows closed. The data are also grouped according to the two general climate categories used in Reference 19, i.e., "warm" and "cold" climates. Table 5-5 presents a summary listing of the data given in Reference 20. It should be noted that the data shown on Table 5-5 represent mean noise-reduction values which have been computed from weighted-average noise reduction values reported in the various investigations included in the data analyses. This weighting is based on the number of rooms associated with a given average noise-reduction value (see Table II in Reference 20).

5.2 OFFICE/PUBLIC SERVICE AND COMMERCIAL/APARTMENT HIGH RISE STRUCTURES

Compared with the single-family residential structures, there is very little building noise-reduction data available for office/public service and commercial/apartment high rise structures. However, some data have been reported for aircraft and highway traffic noise sources.[17,20,21] Table 5-6 and Table 5-7 present summary listings of these data.

TABLE 5-3 BUILDING NOISE REDUCTION VALUES IN TERMS OF AVERAGE OCTAVE-BAND SOUND PRESSURE LEVEL FOR SINGLE-FAMILY RESIDENTIAL STRUCTURES (From Reference 19)

CLIMATE/WINDOW CONFIGURATION CATEGORY	SOUND PRESSURE LEVEL (dB) FOR OCTAVE-BAND CENTER FREQUENCIES (Hz)							NUMBER OF MEASUREMENTS USED TO COMPUTE AVERAGE
	63	125	250	500	1000	2000	4000	
Warm/Open	11.2	9.0	11.8	12.8	11.7	11.1	12.8	15
Warm/Closed	17.4	18.1	20.5	22.2	25.3	26.9	28.9	28
Cold/Open	14.0	14.4	15.6	16.3	18.0	19.3	20.3	31
Cold/Closed	17.0	18.7	21.7	26.3	30.2	33.6	33.4	32
Average for:								
Warm/Open and Closed	15.3	14.9	17.5	18.9	20.5	21.4	23.3	43
Cold/Open and Closed	15.5	16.6	18.7	21.4	24.2	26.6	26.9	63
Warm and Cold/ Open	13.1	12.6	14.4	15.2	15.9	16.6	17.9	46
Warm and Cold/ Closed	17.2	18.4	21.1	24.4	27.9	30.5	31.3	60
All Categories	15.4	15.9	18.2	20.4	22.7	24.5	25.5	106

TABLE 5-5 BUILDING NOISE REDUCTION VALUES IN TERMS OF (WEIGHTED) AVERAGE A-WEIGHTED SOUND LEVEL FOR SINGLE-FAMILY RESIDENTIAL STRUCTURES (From Reference 20)

NOISE SOURCE	CLIMATE/WINDOW CONFIGURATION CATEGORY	A-WEIGHTED SOUND LEVEL, dBA	NUMBER OF ROOMS ASSOCIATED WITH WEIGHTED AVERAGE COMPUTATION
Aircraft	Warm/Open	12.1	14
	Warm/Closed	26.4	132
	Cold/Open	18.4	26
	Cold/Closed	27.6	26
Highway	Warm/Open	*	*
	Warm/Closed	25.0	11
	Cold/Open	11.2	29
	Cold/Closed	22.8	33
Aircraft and Highway	Average for:		
	Warm/Open and Closed	25.0	157
	Cold/Open and Closed	19.9	114
	Warm and Cold/ Open	14.1	69
	Warm and Cold/ Closed	25.9	202
	ALL CATEGORIES	22.9	271

* No data presented.

TABLE 5-6 BUILDING NOISE REDUCTION VALUES FOR OFFICE/PUBLIC SERVICE STRUCTURES

BUILDING TYPE	NOISE SOURCE	AVERAGE NOISE REDUCTION dBA	NUMBER OF MEASUREMENTS USED TO COMPUTE AVERAGE	SOURCE OF DATA
Schools	Aircraft			
Grade	Approach	20.8	22	
Grade	Takeoff	30.0	21	
High	Approach	22.2	15	Reference 17
Average for all School Types	--	24.5	58	
Schools				
Grade	Aircraft	22.0	264	
Junior High	Aircraft	23.2	48	Reference 21
High	Aircraft	20.0	60	
Average for all School Types	Aircraft	21.8	372	
Hospitals	Aircraft	24.8	105	Reference 21
Average for all Office/Public Service Structures	Aircraft	22.7	535	References 17 and 21

TABLE 5-7 BUILDING NOISE REDUCTION VALUES FOR COMMERCIAL/APARTMENT HIGH RISE STRUCTURES

BUILDING TYPE	NOISE SOURCE	AVERAGE NOISE REDUCTION dBA	NUMBER OF MEASUREMENTS USED TO COMPUTE AVERAGE	SOURCE OF DATA
Motel Rooms	Aircraft	19.3*	3	Reference 17
Motel Rooms	Aircraft	25.4**	5	Reference 17
Average for all Motel Rooms	Aircraft	23.1	8	Reference 17
High-Rise Apartments	Highway Traffic	18.5*	7	Reference 21
High-Rise Apartments	Highway Traffic	30.5**	1	Reference 21
Average for all High-Rise Apts.	Highway Traffic	20.0	8	Reference 21
Average for all Commercial/ Apartment High-Rise Structures	Aircraft and Highway Traffic	21.6	16	References 17 and 21

* Windows Opened.
** Windows Closed.

5.3 EVALUATION OF STUDY RESULTS

Building noise-reduction data were collected and evaluated for various building-structure types: 1) single-family residential, 2) office/public service, and 3) commercial/apartment high rise. Both earlier and more resent publications concerning building noise-reduction investigations were considered in the data evaluation.

5.3.1 Single-Family Residential Structures

Based on an evaluation of currently available data (see Tables 5-1, 5-2, 5-4, and 5-5), the average noise-reduction value for single-family residential structures, expressed in terms of A-weighted sound level (L_A), is approximately 20 dB. This level is derived from building noise-reduction data reported for various types single-family residential structures located thourghout the United States. These data represent typical outdoor-to-indoor noise attenuation afforded by building structures exposed to aircraft or highway traffic noise sources. Although no data were reported for construction equipment, it is expected that the range of noise spectra produced by aircraft and highway traffic noise sources is not significantly different from that produced by construction equipment. Therefore, the 20 dB noise-reduction value determined for single-family residential structures is assumed to be applicable to construction equipment noise sources.

5.3.2 Office/Public Service and Commercial/Apartment High Rise Structures

Based on an evaluation of currently available data (see Table 5-6 and 5-7), the average noise-reduction value for office/public service and for commercial/apartment high rise structures, expressed in terms of A-weighted sound level, is 20 dB. Data used to derive this noise-reduction level represent typical outdoor-to-indoor noise attenuation afforded by building structures exposed to aircraft and highway traffic noise sources. However, the 20 dB noise-reduction value is assumed to be applicable to construction equipment noise sources.

5.3.3 Summary of Study Results

Based on an evaluation of currently available data concerning "typical" or average building noise-reduction values, it appears that all construction site noise impact calculation should be performed relative to an L_{dn} outdoor threshold of 65 dB. The suggested use of a 65 dB outdoor threshold for all impact calculations is based on the finding that a representative average building noise-reduction value of 20 dB is applicable to single-family dwellings as well as other larger and heavier building structure types.

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REFERENCES

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APPENDIX A

APPENDIX A

DESCRIPTION OF THE DATA REQUIREMENTS
AND COMPUTATIONAL PROCEDURES USED TO
DETERMINE CONSTRUCTION EQUIPMENT USAGE FACTORS

This appendix presents a detailed description of the data requirements and computational procedures used to determine construction equipment usage factors.

A.1 Data Requirements

Equipment usage factors are a function of the following construction site and equipment usage parameters:

1. Average number of hours per day that the machine operates during each construction phase.
2. Fraction of each construction phase duration that the machine operates.
3. Fraction of all sites for each site type on which machine is used.

A.2 Computational Procedure and Description of Data Elements

The following equation is used to determine the usage factors for each construction equipment type:

$$UF = \left|(ANH) \cdot (FCP) \cdot (FAS)\right| /8 \qquad (1\text{-}A)$$

where

UF = construction equipment usage factor,

ANH, FCP and FAS are the construction site and equipment usage parameters 1, 2 and 3, respectively as defined in Section A.1.

The factor of 8 in the above equation represents the assumed number of hours per day of construction activity.

A.3 Example Calculation

The following example is a step-by-step procedure used to determine the forklift truck usage factor for the residential site type-foundation construction phase:

Step 1. Using Table 2-3 in Section 2.3, determine the average number of hours per day and the fraction of the phase duration that the machine operates.

These values are:

ANH = 1.83

FCP = 0.247

Step 2. From Table 2-4 in Section 2.4.2, determine the fraction of sites on which the machine is used. This value is:

FAS = 0.30

Step 3. Using equation 1-A, compute the equipment usage factor, UF.

$$
\begin{aligned}
UF &= \left[(ANH) \cdot (FCP) \cdot (FAS)\right] / 8 \\
&= \left[(1.83) \cdot (0.247) \cdot (0.30)\right] / 8 \\
&= 0.0170
\end{aligned}
$$

APPENDIX B

APPENDIX B

COMPUTATIONAL PROCEDURES USED TO DETERMINE THE POPULATION TRANSFER BETWEEN SMSA GEOGRAPHICAL COMPONENTS AND THE CHANGE IN POPULATION DENSITY DURING THE NORMAL DAYTIME WORK PERIOD

This appendix presents a detailed description of the procedures for determining the population transfer between SMSA geographical components and for calculating the population density and percent change for the area outside SMSAs.

B.1 Procedure for Determining Population Transfer Between SMSA Geographical Components

The following is a step-by-step procedure for determining worker transfer between SMSA geographical components (SMSA region categories) during the normal daytime work period:

Step Number	Procedure
1	For SMSA Region under investigation, list all fundamental geographic components listed in Journey to Work (Ref. 7).
2	For each geographic component, find 1970 population, area, and number employed workers from County and City Data Book (Ref. 10).
3	Determine baseline population density for each geographic component.
4	Place each geographic component into one of four SMSA regional categories (noting name, population, and area) according to the following criteria:

CATEGORY	CRITERIA
High-Density Central Cities (High-Density Urban Centers)	Population >400,000 and density >8,500
Low-Density Central Cities (Low-Density Urban Centers)	Population >400,000 and density 3,000 $<\rho\leq$ 8,500
Urban Fringe	Population $\leq$400,000 and density 2,000$<\rho\leq$ 3,000
Outside Urban Fringe	Population $\leq$400,000 and density $\rho\leq$2,000

Step Number	Procedure
5	Determine total population, area and density for each category.
6	Using the Journey to Work book, distribute all worker transfers as appropriate. For example: X workers living in B and working in A — 1) subtract X from SMSA regional category containing B, and 2) add X to SMSA regional category containing A. Include workers living outside SMSA working in the various geographic components being analyzed.
7	A. Determine the number of employed workers living in the Urban Fringe and SMSA areas outside the Urban Fringe by using data found in Step 2 and results of Step 4.
	B. Sum these two categories and find percentage of employed workers in each (of the two categories) based on this sum.

C. Allocate 27 and 73 percent of the "Workers living in the SMSA working outside it" in the Journey to Work publication to the Central City and Outside the Central City (Urban Fringe and SMSA Areas Outside Urban Fringe), respectively. (These percentages are based on data presented in Table 3-1 in Section 3.1).

D. Determine the number of workers living in the Urban Fringe and the number living in SMSA Area Outside the Urban Fringe but working outside the SMSA by multiplying the total number of employed workers for both region categories, as determined from step 7C, by the percentages for each region category found in Step 7B.

E. Subtract the resultant number of workers found in Steps 7C and 7D for the Central City, Urban Fringe, and Outside the Urban Fringe from the appropriate region categories and add them to the Outside SMSA region category.

8 A. Find Total Employed Persons in each SMSA geographic component using data from Step 2 and results of Step 4 and 7.

B. Find percentage of Total Employed Workers in each SMSA geographic component.

C. Using Journey to Work publication, find the number of workers living in the SMSA but not reporting their place of employement and multiply this number by percentages found in Step 8B.

D. Find the percent of workers living in each SMSA geographic component which worked in another (using data from Step 6).

E. Multiply the number of workers found for each component in Step 8C by percentages found in Step 8D and allocate as appropriate.

9 Sum all worker transfers made during Steps 6, 7 and 8 and add to initial population.

10 Repeat Steps 1 through 9 for all sample High- and Low-Density SMSA categories.

11 Determine the normal daytime work period population density and percent change for the five SMSA Region Categories using the relationships presented in Section 3.3.

B.2 Calculation Procedure for Determining Population Density and Percent Change for the Area Outside SMSAs

The average population density and percent change for the area outside the SMSAs during the normal daytime work period was estimated from the following population and land area data:

1. estimated population density and total land area for each of the four region categories within the SMSAs,
2. approximate total U.S. population and land area

The data requirements identified in item 1 and 2 above were determined from the results presented in Section 3 of this study and Table 8 in Reference 2. Based on this data, it was estimated that the total population inside and outside the SMSAs during the normal daytime work period was 146.8 and 63.2 million people, respectively. The population outside the SMSAs was determined by subtracting the population inside the SMSAs (computed from region category population densities and land areas) from the total U.S. population. The approximate total land area outside the SMSAs was estimated to be 3.35 million square miles. Using the outside SMSA population and land area data, the average normal daytime work period population density and percent change were determined to be approximately 19 people per square mile and -5.7, respectively.

APPENDIX C

APPENDIX C

DEVELOPMENT OF REVISED POPULATION DENSITY VALUES BY CONSTRUCTION SITE TYPE AND BY SMSA REGION CATEGORY

This appendix presents a discussion of the procedure used to determine the revised population density values by construction site type and by SMSA region category.

C.1 Key Assumptions

In determining revised population density values, the following assumptions were made:

1. Each SMSA region category is composed of several basic land use categories, three of which are: 1) residential, 2) commercial, and 3) industrial.
2. Construction activities associated with the four site types considered in the noise impact model are performed in land use categories in accordance with the following:

Construction Activity/ Site Type	Land Use Category
Residential	Residential
Office/Public Service	Residential, Commercial, and Industrial
Industrial/Commercial	Industrial and Commercial
Public Works	Residential, Commercial, and Industrial

3. The baseline population density values (as defined in Section 3.1) for each SMSA region category were determined from the total residential population and total land area allocated to that category.
4. Transfer of population (workers) is primarily from the residential to the commercial and industrial land use categories.
5. Public works construction activities occur in all land use categories; the population density associated with the public works site types in a given SMSA region category is the average of the population densities associated with the other three site types.
6. Due to the relatively small change in the population density value for areas outside the SMSAs during the normal daytime work period (one person per sq.mi.), an average population density value is assigned to all land use categories in this region.

7. Percent changes in population density for all land use categories in the central cities and the SMSA areas outside the central cities are applicable to the same land use categories in the high- and low-density urban centers and the urban fringe and SMSA areas outside the urban fringe, respectively.

C.2 Data Development

Using data presented in Table 3-1 in Section 3.1 and Tables 34 and 36 in Reference 9, it was found that, for SMSAs of 250,000 or more[1], the number of employed workers represented approximately 38 and 39 percent of the total population living in the central cities and the SMSA areas outside the central cities, respectively. Since it is assumed that these workers live in the residential land use categories and transfer from this category to commercial and industrial land use categories, the percent change in residential population density for the central cities and the SMSA areas outside the central cities is proportional to the reductions in total residential popualtion. The percent change in population density for the commercial and industrial land use categories is determined from the data presented in Table 3-2 in Section 3.4.1 for the region categories inside the SMSA. These data are assumed to be applicable to both land use categories where office/public service and industrial/commerical construction activities occur. It should be noted that although some office/public service sites are most likely located in residential land use categories, it is assumed that the major proportion of these site types are in commercial and industrial land use categories.

The percent change in population density for all land use categories in areas outside the SMSAs is -5.7. This value was determined from the population transfer analysis presented in Section 3.

Table C-1 presents a summary of the percent changes in baseline population density by site type and by SMSA region category.

[1]SMSAs of 250,000 or more represent approximately 90 percent of the total SMSA population.

Table C-1. PERCENT CHANGE IN POPULATION DENSITY BY CONSTRUCTION SITE TYPE AND BY SMSA REGION CATEGORY

Construction Site Type	SMSA Region Category				
	High-Density Urban Centers	Low-Density Urban Centers	Urban Fringe	SMSA Areas Outside the Urban Fringe	Outside SMSA
Residential	-38.0	-38.0	-39.0	-39.0	-5.7
Office/Public Service	+13.4	+ 8.4	- 0.4	- 8.1	-5.7
Industrial/ Commercial	+13.4	+ 8.4	- 0.4	- 8.1	-5.7
Public Works	- 3.7	- 7.1	-13.3	-18.4	-5.7

APPENDIX D

APPENDIX D

DURATION OF CONSTRUCTION SITE ACTIVITY BY SITE TYPE AND SURROUNDING POPULATION DENSITY

This appendix presents a complete listing of the data used to:

- compute mean census tract population density values by site type,
- derive relationships between duration of construction site activity and census tract population density by site type.

The data contained in the listing were developed from construction project records and census publications prepared by the Office of Research and Statistics (ORS) - Community Development Branch of Fairfax County, Virginia. The data listing contains 1,984 individual construction project records arrayed in accordance with the following format:

Column No.	Description of Information
1	Census Tract Population Density (people/sq.mi.). A zero in this column indicates that the population density value could not be determined from available data. Records with a zero in the population density column were not included in the population density analyses presented in Section 4.
2	Construction Site Type Identifier: 2 - Office/Public Service 3 - Industrial/Commercial 10 - Single-Family (Residential) 11 - Multi-Family (Residential) 12 - Town House (Residential)
3	Duration of Construction Site Activity (months).

Column Number

1	2	3
46	3	3
46	3	5
7204	2	9
1147	3	7
2212	2	3
1332	2	12
1617	2	12
105	3	14
2041	3	7
167	3	5
29	2	4
10327	2	7
29	2	6
1646	3	6
1870	2	14
2908	3	5
4742	3	8
4742	3	7
5684	2	7
4848	3	7
328	3	11
1512	3	4
1512	3	9
1087	3	10
1094	2	11
1096	3	7
1094	2	14
5264	3	8
1310	3	6
8735	2	8
5124	3	14
201	3	6
201	3	6
201	3	6
196	2	7
2643	3	12
3660	2	12
3660	2	9
3486	2	14
5033	3	7
10542	3	11
8556	2	11
2355	2	9
7565	2	10
1428	2	10
2345	3	10
6662	3	10
6662	3	11
2345	2	10
3876	3	4
2860	3	8

1553	3	4
2267	2	6
1665	3	10
0	3	6
28	3	6
28	3	9
861	3	7
928	2	3
3660	3	8
4500	3	11
367	3	8
3444	3	6
243	3	11
0	2	12
0	3	4
0	3	12
0	3	16
0	2	9
0	3	11
0	2	10
0	2	14
0	2	13
0	3	9
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0	2	12

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0	2	36
243	3	5
350	3	8
109	2	12
2266	2	17
167	2	8
3657	3	10
28	2	4
635	3	4
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1587	3	3
1587	2	10
1080	2	16
11127	3	8
6252	3	8
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27	3	13
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0	3	11
0	3	12
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0	3	12
0	3	11
0	3	8
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0	3	12
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0	3	8
0	2	4
0	3	5
0	3	4
56	10	16
56	10	23
56	10	7
58	10	10
0	10	21
58	10	11
0	10	49
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2081	12	8
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2077	12	9

2077	12	12
1871	10	6
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2086	10	24
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7818	10	6
7175	10	6
3876	10	3
6543	10	11
7818	10	12
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11000	12	6
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207	10	7
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196	10	11
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196	10	6
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3840	12	8
3840	12	8
1109	10	6
1363	10	5
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1363	10	8
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0	10	20

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9940	10	5
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562	10	12
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2731	10	5
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0	11	8
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0	11	9
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14250	11	15
14250	11	11
14250	11	15

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REPORT ON THE PROPOSED REDUCTION IN NOISE LEVELS AT THE SEATTLE-TACOMA AIRPORT

Prepared by Alice H. Suter, Ph.D.
for the Regional Commission on Airport Affairs
October 26, 1994

To: PSRC Expert Panel on Noise and Demand/Systems Management

Panel's Request to the Public for Information

This report will address the Panel's request #2: "Detailed descriptions of any technical reasons why achievement of the noise reduction performance objectives of the Noise Budget and Nighttime Limitations Program established by the POS would not be expected to produce a significant reduction in real noise impacts on-the-ground."

The key word in this request is "impacts." The dictionary defines "impact" as "the striking of one body against another" (Urdang and Flexner, 1968). In this case one body is the sound pressure generated by aircraft operations and the other body is the community of individuals living nearby. Interestingly, the Mestre Greve (1994) report commissioned by the Port of Seattle is solely concerned with noise measurement and prediction and makes no mention of the impact on the community. But it is meaningless to describe the details of the noise stimulus without describing its impact on the recipients.

Another significant omission from the Mestre Greve report and in much of the discussion of the noise climate at Sea-Tac is the proposed third runway. The Procedural Order in the matter of the Expert Arbitration Panel quotes Resolution A-93-03 to say that "the region should pursue vigorously ... a third runway at Sea-Tac" and that the third runway "shall be authorized by April 1, 1996 ... [W]hen noise reduction performance objectives are scheduled, pursued and achieved based on independent evaluation, and based on measurement of real noise impacts." This statement implies that the approval of the third runway is an accomplished fact once the Port has established a "significant reduction of real, noise impacts on-the-ground." Although the prospect of the third runway is seldom mentioned by the Port or its consultant, its specter looms over the community and cannot be separated from the impact of existing noise exposure or of that predicted for 1996.

This report will show that the performance objectives of the Noise Budget and Nighttime Limitations Program cannot be expected to produce a significant reduction in real noise impact on the community. There are a number of reasons for this:

1. The predicted decreases in ANEL of 1.55 dB and DNL of 2.1 dB may not occur because they are within the margin of error of such predictions.

2. Even if they do occur, these decreases in ANEL and DNL will not be perceptible to residents.

3. The predicted decreases in ANEL and DNL will not produce a significant decrease in adverse effects on the community.

4. Using the DNL metric alone is not sufficient to predict the total impact.

5. The proposed reduction is grossly insufficient because it reduces noise exposures from levels that are unacceptable to levels that are still unacceptable.

1. <u>Margin of error</u>

In her testimony before the Panel, Susan Evans pointed out the well-known fact that aircraft noise exposure forecasting is not an exact science. While consultants usually do the best job they can, the outcome is influenced by such a wide variety of factors that the actual levels rarely match the predictions. These factors include the exact mix of Stage II and Stage III aircraft, whether the Stage III aircraft are hush-kitted, re-engined, or manufactured, and if they are manufactured, where they fall in the range of noisy to quiet within the Stage III category. Numbers of operations may also change, as Ms. Evans pointed out, to say nothing of the increased number of operations that could be expected if a third runway were constructed.

Panelists Martha Langelan and Bill Bowlby queried Paul Dunholter from Mestre Greve about the use of the standard noise modeling technique (INM), whether or not it had been tailored to the Sea-Tac airport, and the extent to which it has overpredicted or underpredicted noise levels. Mr. Dunholter replied that it had not been tailored to Sea-Tac, that most aircraft types were actually measured to be within plus or minus 3 dB and that the total DNL was "in the range of 3 dB."

It seems ludicrous to base major policy decisions on a predicted noise reduction obtained using a standard (unmodified) prediction model with a margin of error that is greater than the predicted noise reduction itself. Even if the DNL margin of error were a total of 3 dB, meaning plus or minus 1.5 dB, this margin of error is virtually the same as the predicted 1.55 dB ANEL reduction and is dangerously close to the predicted average DNL reduction of 2.1 dB.

2. <u>The predicted decrease will not be perceptible.</u>

FICON:

Neither a decrease in ANEL of 1.55 dB nor a decrease in DNL of 2.1 dB will be perceptible to the airport neighbors. This is despite Mr. Dunholter's statement that the FICON document uses "1.5 dB as a threshold of significance [of]... change" and that the FAA uses 1.5 dB as a guideline for the preparation of an EIS. Actually, the drafters of FICON's technical report use a 3-dB *increase* at DNL 60 dB and a 1.5 dB *increase* at DNL 65 dB to *trigger the need for further analysis*. There is nothing in the report to indicate that FICON considers 1.5 dB a significant *decrease* in noise exposure. The report does state that although it is difficult for individuals to detect a 3-dB change, a community would find such a change "clearly noticeable." It cites no scientific evidence to support this point, however, only a personal communication from William Galloway (FICON, 1992).

FAA Order 1050.1 does establish an *increase* in DNL of 1.5 dB in noise sensitive areas as a trigger for further analysis, but the FICON report cites no evidence to support this level. It appears to be a policy decision only, although probably a judicious one because it refers to proposed increases in noise exposure level.

Panelist Bill Bowlby states quite rightly that a decrease from a DNL of 90 to a DNL of 87 would not be particularly noticeable, (even though the sound energy would be cut in half), but the same reduction in DNL could be achieved by cutting the number of operations in half, and this would be clearly noticeable.

Sound energy vs. loudness:

The statement in the Mestre Greve report that a reduction in ANEL of 1.55 dB amounts to a reduction of 30 percent is misleading. When only sound energy is considered, a reduction of 3 dB is indeed a reduction of 50 percent, but people's ears do not perceive the same increments. It is a well known concept in psychoacoustics that it takes a reduction of 10 dB to achieve a 50 percent reduction in loudness (Stevens, 1957, 1972; Zwicker and Scharf, 1965). Therefore, a reduction of 1.55 dB amounts to a reduction of only about 8 percent rather than 30 percent, and it is highly unlikely that anyone would notice it. This is why Mr. Bowlby was correct in his assumption that even a 3-dB reduction in sound energy would not be particularly noticeable, whereas a reduction in numbers of operations would be. In this case, people are responding to something besides DNL.

The same principle holds true for judgements of noisiness, (sometimes referred to as "perceived noisiness"), which have been used to assess peoples' reactions to aircraft noise. Kryter (1984) has found that the 10-dB increase per doubling and halving of noisiness applies up to peak indoor levels of about 80 dB(A), but after that the function becomes somewhat steeper.

What is detectable?

Experiments show that the smallest increment in sound level that people can detect is about 0.5 to 1 dB *in the laboratory*. These loudness judgements are based on the comparison of sounds that occur very close together in time, nearly simultaneously. Investigators have found, however, that after an interval of about one second, the judgements become contaminated by one's ability to remember (eg. Florentine, 1986). If laboratory subjects have difficulty remembering the loudness of *specific* sounds after a period of one second, it goes without saying that it would be impossible to remember such small increments in *averaged* sounds (like DNL) over a period of years, such as from 1990 to 1996. Moreover, as we will point out, these judgements become influenced by much more than one's memory.

The question arises, then as to the size of a change, and specifically a decrease, in average noise level that is detectable by a community. The evidence is not at all clear. For example, Fidell and Silvati (1991) measured the long-term annoyance from noise in the vicinity of the Atlanta airport in the residents of a large number of homes either treated or untreated with acoustical insulation. The authors estimate that the acoustical insulation added about 5 dB to the transmission loss of a typical wood frame structure. The investigation found no significant difference in the annoyance of residents in treated as compared to untreated homes. Therefore, the 5-dB reduction in DNL (at least indoors) was not significant.

With respect to decreases in road-traffic noise, de Jong (1990) reports that in general, no significant effect occurs with minor changes, defined as 3 dB or less, but that a positive effect may be expected if the reduction from noise insulation is 12 dB or more. De Jong points out, however, that since costs are involved in erecting barriers or installing insulation, more noise reduction may be necessary for a comparable decrease in annoyance than if there was a reduction in the source itself. It appears, from at least these limited data, that a reduction of somewhere between 5 dB and 12 dB is necessary to produce a noticeable change in the community's reaction. But a reduction in annoyance is even more unlikely in the present case because of certain non-acoustical factors.

3. <u>The predicted decrease will not result in a significant decrease in adverse effects</u>.

Non-acoustic variables:

The traditional method of evaluating the impact of aircraft/airport noise on communities has been to conduct attitudinal surveys by telephone and, after an analysis of the data, to determine the percentage of the population "highly annoyed" as a function of given levels of aircraft noise in DNL. Research projects in recent years point to the fact that much of the variability in the resulting data is due not only to noise exposure level but to a limited number of attitudinal variables. According to Job (1993), some 60 percent of the variance in group data and only 9-29 percent of the variance in individual data is explained by noise exposure. Much of the rest of the variance is accounted by the following attitudinal factors (Fields, 1993):

1. Fear that an aircraft may crash.

2. A belief that the aircraft noise could be prevented or reduced by designers, pilots, or authorities related to the airlines.

3. An expressed sensitivity to noise.

In his extensive study of these non-acoustic factors, Fields (1993) does not reject the assumption that there will be changes in annoyance following changes in noise level. The point is that any such changes are likely to be greatly influenced by these three factors: fear, perception of preventability, and sensitivity.

The Schultz curve:

The criterion used to predict the percentage of a community that will be "highly annoyed" by given levels of aircraft/airport noise is a function commonly known as the "Schultz curve," named for the acoustical expert who developed it. Schultz (1978) analyzed a number of studies, plotted some 161 data points, and developed a predictive equation based on a regression analysis of these data. The studies included noise from airports, highways, road traffic, railroads, and tram lines.

Recently, a revision of the Schultz curve was published by Fidell, Barber, and Schultz (1991), which added 15 new studies, making a total of 453 data points. The new curve predicts slightly more annoyance than the original curve at a DNL of about 75 dB and below, and slightly less than before above that point. A relatively similar update of the Schultz curve appears in the FICON (1992) report, which we will assume to be the most recent version.

According to the latest version of the Schultz curve, the percentage of those highly annoyed residents exposed to the Sea-Tac baseline ANEL of 74.52 dB would have been 35.52 percent, and the percentage exposed to the predicted level of 72.97 dB in 1996 would be 31.05 percent, a decrease of 4.54 percent. Figure 1 shows the predicted percentage of the population highly annoyed according to year, with ANEL plotted in the upper part of the graph. (The reductions in both parameters are barely noticeable on the graph.)

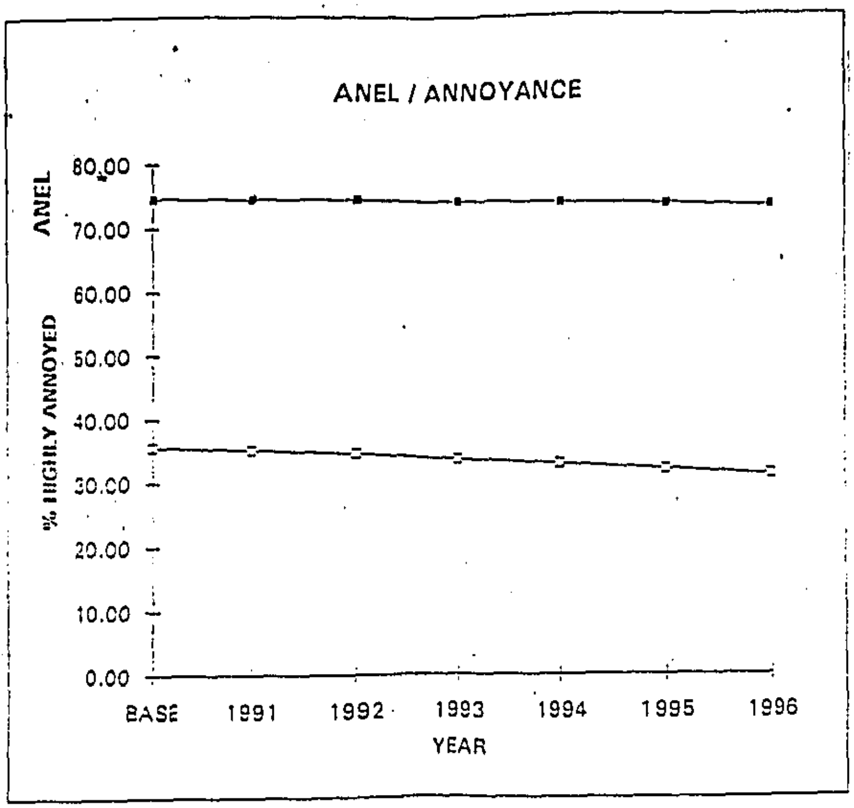

Fig. 1. Percent highly annoyed (open squares) due to corresponding ANEL levels (filled squares). ANEL data are taken from Table 3 of the Mestre Greve report (1994) and the estimated percentages of highly annoyed are calculated from the equation for the updated Schultz curve (FICON, 1992).

These predictions assume that the calculated noise reductions would be realized, that the Schultz curve accurately describes the population highly annoyed, and that any intervening variables would not be important -- three highly questionable assumptions.

In fact, if the community had been surveyed in 1990 and were to be again in 1996, it would be unlikely that there would be any decrease at all in the percentage highly annoyed. This is true, at least in part, because of the magnitude of the contribution of the three attitudinal variables discussed above. In light of the ever-present threat of the new runway, these attitudinal variables are bound to be critical factors, especially the community's perception of preventability.

4. <u>DNL alone is not sufficient to describe the impact</u>.

As many witnesses have testified, the DNL metric does not tell the whole story. While it is useful in making certain predictions, the way it is used has many shortcomings, and the metric itself needs to be supplemented in many cases.

Other descriptors, such as the "Sound Exposure Level" (SEL) and the "Time Above" (TA) statistic are often recommended for specific locations where speech communication is important (FICON, 1992). There are some 29 schools and colleges located within the DNL 65 dB contour, and aircraft noise is bound to have a serious impact on these students and their teachers. This impact must be assessed before any proper analysis of the current or predicted conditions can occur, let alone any ideas about the installation of a new runway. The use of supplemental measures, such as SEL or TA would be necessary for this assessment.

Another critical element in describing the impact is the number of aircraft operations. In many circumstances, people are more likely to notice changes in the number of operations than in the overall DNL. This is due in part to the need to reduce noise level by 10 dB (rather than 3 dB) to effect a halving of loudness or noisiness. A 10-fold reduction in the number of overflights would also amount to a halving of sound energy, but it would be considerably more noticeable and have a much greater benefit. To state it slightly differently, a Stage III plane is typically about half as *loud* as a Stage II plane, even though it puts out only about one-tenth the sound energy (Stewart, 1993).

There are two particular circumstances where people are also likely to notice changes in numbers of operations more than changes in DNL. One is in places like schools, where speech communication is critical and the number of interruptions is at least as important as the sound level and the length of each overflight. Another is in situations where people like to spend time out of doors. Acoustical consultant Noral Stewart has found that in places where people put a high value on enjoying their property out of doors, a single noisy Stage II plane would be preferable to several quieter Stage III planes, even though they might have the same total energy. The reason is that the recipient could "get it over with" and enjoy the period of respite (Stewart, 1993).

This is an important point when considering the impact on the Sea-Tac neighbors, where the beautiful natural setting is a preeminent attraction. With Mount Rainier on one side and Puget Sound on the other, most families in the area want to spend time on their decks. In addition to their homes, residents want to spend recreational and leisure time elsewhere in the impacted area, such as the harbor in Des Moines and the winding paths along the Sound.

Despite their importance, numbers of operations have been omitted from the proposed noise reduction objectives. Perhaps one reason for this is that the Mestre Greve report shows gradually increasing numbers of operations between the base year and 1993, and this trend could very well continue into 1996 and beyond. More importantly, nothing is said about the projected increase in operations that is destined to accompany a third runway.

5. Reducing the levels from unacceptable to unacceptable.

Severity of exposure:

The Port's projections showing shrinking noise contours between 1991 and 1996 look impressive, but the public should not be misled for a number of reasons. First, as mentioned above, the achievement of the 1996 contours is questionable, and even if they are achieved, the projected reduction in ANEL of only 1.55 dB (or 2.1 dB in the average DNL), is not likely to be noticeable. Also, it is important to remember that noise exposure contour lines are not break points, but represent locations on a continuum of noise levels. This means that moving from just inside the DNL 65 dB contour to a DNL of 63 or 64 dB cannot be expected to provide instant relief, and, for that matter, cannot even be expected to be noticeable.

The fact is that very many residents living within the impacted areas will be exposed to extremely high, barely tolerable levels of noise. Even if the predictions turn out to be accurate, the Port estimates that in 1996, 1300 people will still reside within the DNL 75 dB contour, which has been labeled a "severe exposure" and "unacceptable" by HUD, and by FAR Part 150 as unacceptable for residential land use, even after the incorporation of noise attenuation. Schools and other noise sensitive properties will also be located in this area.

If the predictions are correct, nearly 14,000 people will reside in noise levels above DNL 70 dB, considered "significant exposure" and "normally unacceptable" by HUD. An estimated 44,000 people exposed above DNL 65 dB will reside in areas that are considered "normally unacceptable" by HUD, and, according to FAR Part 150, that are "incompatible with residential or school land uses unless measures are taken to achieve additional noise level reductions." (FICON, 1992)

The impact is more severe than the Schultz curve would predict:

According to the Schultz curve, approximately 31 percent of the exposed population would be highly annoyed at the predicted DNL of 72.97 dB in 1996. But several investigations have shown that the percentage of persons highly annoyed by aircraft noise is considerably higher than that from other types of transportation noise. The Schultz curve, however, includes all types of transportation noise, with the understandable result that there is a large amount of variability around the single regression curve.

Figure 2, from Fidell *et al.* (1991) shows the authors' version of the Schultz curve using a quadratic fitting function, which they found accounts for 44 percent of the variance. (Note the wide scatter of data points.) The data in Figure 3 (also from Fidell *et al.*, 1991) should help to explain this variability. The data were collected by Canadian researchers (Hall, *et al.*, 1981) who contrasted annoyance from aircraft noise in the vicinity of the Toronto airport to annoyance from road traffic noise. The graph shows the aircraft noise data points and road traffic noise data points plotted alongside the 1978 Schultz curve. This figure clearly shows that annoyance due to aircraft noise is considerably greater than it is for comparable levels of road traffic noise. Fidell and his colleagues (1991) studied the data from several other airports and found that the aircraft noise data points fell substantially above the Schultz curve in nearly every case.

European and other international noise experts have also found that the Schultz curve underestimates annoyance due to aircraft noise. Dutch researcher Passchier-Vermeer (1993) has summarized the results of various studies of transportation noise. Figure 4, from Miedema (1992) (in Passchier-Vermeer, 1993), shows the relative annoyance from aircraft noise (A), highway noise (H), other road traffic noise (O), and railroad noise (R). Aircraft noise is clearly the most annoying. Figure 5, also from Miedema, shows the percent "severely annoyed" as a function of DNL from various noise sources. Aircraft noise is the most annoying transportation noise source, although annoyance from impulse noise appears to be even greater. These annoyance functions are contrasted to the 1978 Schultz curve, shown by the dashed line. At a DNL of 70 dB, the Schultz curve predicts about 25 percent of the exposed population to be severely annoyed, whereas Miedema's data would predict greater than 75 percent.

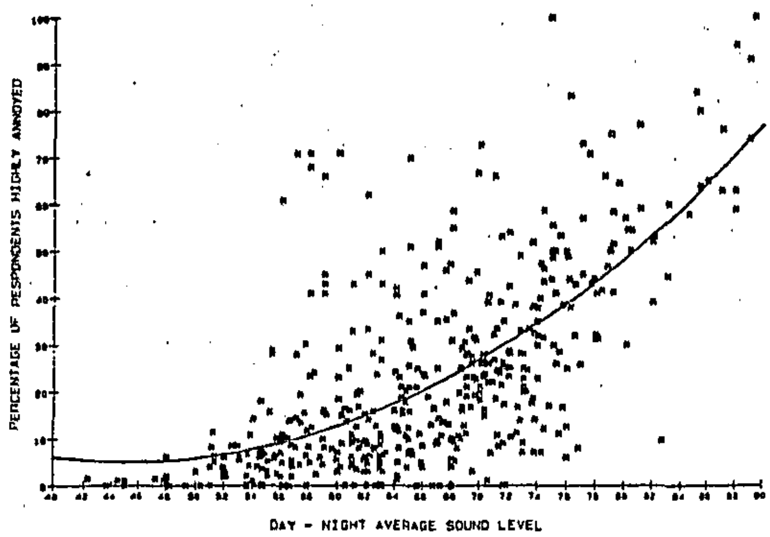

Fig. 2. Updated Schultz curve showing quadratic fit to 453 data points. From Fidell, Barber, and Schultz (1991).

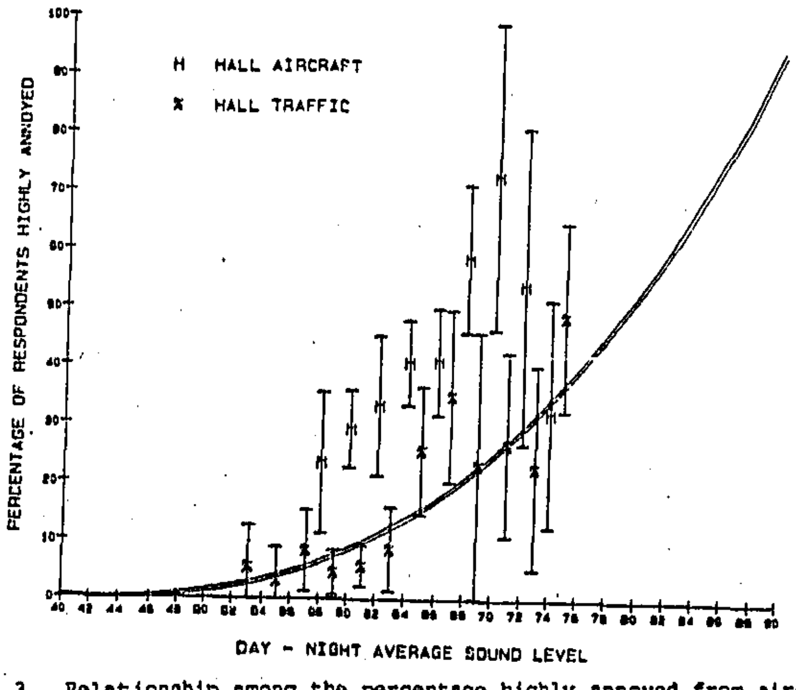

Fig. 3. Relationship among the percentage highly annoyed from aircraft noise (H), road traffic noise (X), and the 1978 Schultz curve. From Fidell Barber, and Schultz (1991).

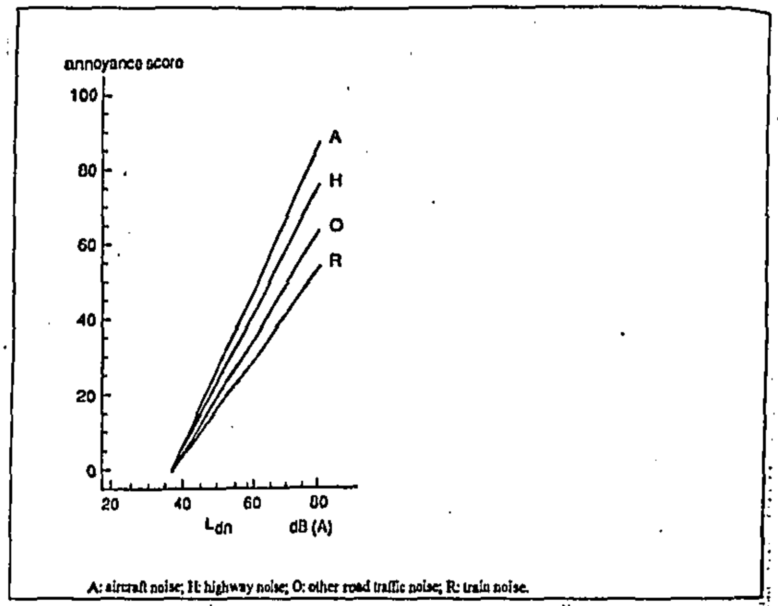

Fig. 4. Relative annoyance as a function of noise level in DNL (L_{dn}) for four types of noise source. From Miedema (1992) as cited by Passchier-Vermeer (1993).

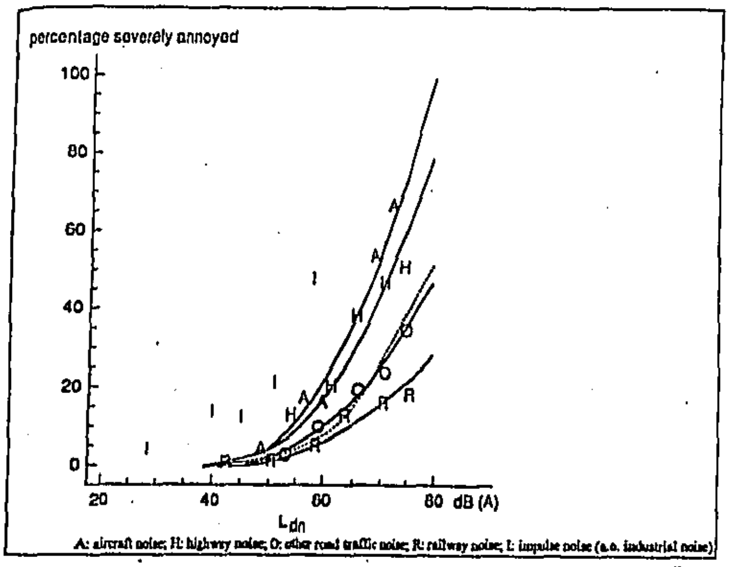

Fig. 5. Percentage severely annoyed by various noise sources as a function of noise level in DNL (L_{dn}). The 1978 Schultz curve is represented as a dashed line. From Miedema (1992) as cited by Passchier-Vermeer. See also Miedema (1993).

Additional research from the Netherlands points to the fact that aircraft noise is more disturbing than other types of transportation noise. A study by de Jong and his colleagues investigated the relative disturbance caused by highway traffic, railroad, and aircraft noise in different activities (de Jong *et al.*, 1992). Table I shows the percentage of people disturbed according to noise level, noise source, and category of activity.

Table I. Percentage of people expressing disturbance during specific activities as a function of 24-hour equivalent sound level (L_{eq}) (from de Jong *et al.*, 1992, translated and cited in Passchier-Vermeer, 1993).

Activity Noise source	L_{eq} 61-65 dB	L_{eq} 66-70 dB
Talking		
Highway traffic	35	45
Railroad traffic	35	35
Aircraft traffic	75	80
Watching TV		
Highway traffic	25	40
Railroad traffic	60	40
Aircraft traffic	60	75
Listening to the radio		
Highway traffic	20	40
Railroad traffic	45	40
Aircraft traffic	45	50
Reading		
Highway traffic	25	30
Railroad traffic	10	10
Aircraft traffic	30	35
Fear		
Highway traffic	35	40
Railroad traffic	5	5
Aircraft traffic	30	40

The table shows that aircraft noise is more disturbing than the other noise sources in nearly every category and that the differences increase with increasing noise level. For example, at average levels (L_{eq}) of 66-70 dB the percentage of people expressing disturbance from aircraft noise during talking and watching TV was nearly twice that for the other noise sources. For listening to the radio and reading it was also higher, but the difference was not as dramatic. The authors have also included fear as a category, and the responses indicate that the levels of fear associated with aircraft noise were higher than railroad noise but about the same as highway traffic.

In Figure 6, Passchier-Vermeer (1993) has plotted the percentage of people whose activities are disturbed by aircraft noise (from de Jong, 1992) alongside the percentage severely annoyed by aircraft noise (from Miedema, 1992). These data provide yet another indicator that the percentage "highly annoyed" predicted by the Schultz curve, greatly underestimates the percentage of people adversely affected by aircraft noise. For example, at an average level of 70 dB, approximately 30 percent are highly annoyed according to the Schultz curve, compared to about 60 percent according to Miedema's curve and up to 80 percent disturbed while talking or watching TV. (While it is true that Passchier-Vermeer has plotted her data as a function of 24-hour L_{eq} rather than DNL, the approximate relationship should be the same.)

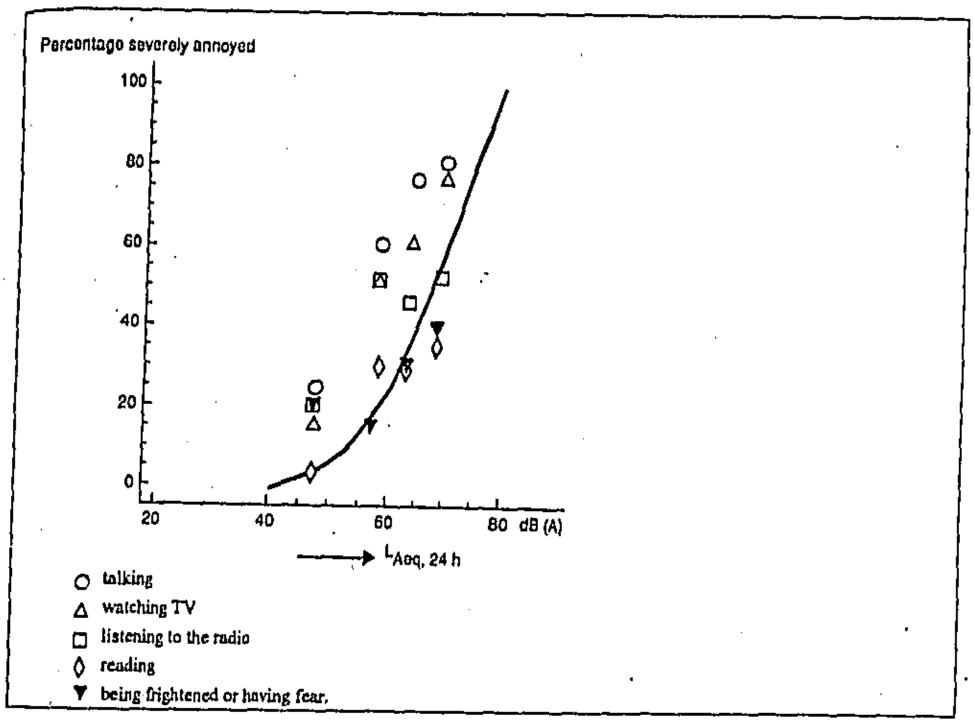

Fig. 6. Percentage severely annoyed (solid line) and the percentage disturbed (data points) by aircraft noise. From Passchier-Vermeer (1993) using the data of Miedema (1992) and de Jong (1992).

In still another recent study of community annoyance, Bradley (1994) found that annoyance from aircraft noise was substantially greater than would have been predicted by the Schultz curve at airports in Canada, Switzerland, the U.K., Norway, Japan, and Australia.

Various reasons have been suggested for the differences between reaction to aircraft noise and to other transportation noise sources. One of the attitudinal factors mentioned above (Fields, 1993) appears to be more directed toward airports than toward other sources: the belief that authorities could prevent the noise. An additional explanation is that aircraft noise is highly intermittent and is therefore less predictable. Several studies have shown that unpredictable noise produces greater adverse effects than predictable noise (eg. Glass and Singer, 1972; Percival and Loeb, 1980). According to a model developed by Canadian researchers (Hall *et al.*, 1985 and Taylor *et al.*, 1987, cited in de Jong, 1990) the differences can be explained by using single events, rather than average noise levels.

Once again, it is clear that DNL does not tell the whole story, especially where aircraft noise is concerned, and that the traditionally used Schultz curve underestimates the impact considerably.

The "highly annoyed" criterion is also an insufficient descriptor of the impact:

Several researchers in psychoacoustics have pointed out that the traditional use of the criterion "highly annoyed" is insufficient to characterize the effects of noise. The use of this criterion has been criticized on the grounds that it is such an extreme measure of community reaction, it treats attitudinal data categorically rather than scaling it, and it fails to analyze the distribution of annoyance (see Job, 1993; Griffiths, 1983). Job (1993) cites the finding by Hede *et al.* (1979) that there are many words that people use to characterize their reactions to noise that do not correspond to "annoyance." Job (1993) points out that "People may react with anger, disappointment, withdrawal, feelings of helplessness, depression, anxiety, distraction, agitation, or exhaustion...." (p. 50) rather than mere annoyance. Thus the inadequacy of the term "annoyance" may account for quite a bit of the unexplained variance.

Perceived control:

Another aspect of reaction to noise that may be closely related to the belief that the authorities could have prevented the noise is that of perceived control over the noise. Studies of the effects of noise on performance and behavior have shown clearly that the severity of human reaction is closely related to one's control or even perceived control over the noise (Glass and Singer, 1972; Singer *et al.*, 1990). A study of the effects of perceived control over aircraft noise showed a highly significant correlation between perceived control with annoyance scores and a smaller but not statistically significant correlation with subjective health scores (Altena, 1989, cited by Passchier-Vermeer, 1993).

Airports, therefore, provide an ideal example of a situation where, if an expansion occurs against the wishes of a community, feelings of lack of control will be a powerful influence on the community's subsequent reaction.

The components of annoyance and other adverse effects:

It is important to remember that expressions of annoyance, disturbance, or being bothered are not merely "attitudes" but are comprised of specific adverse effects as well as feelings. These effects include interference with sleep, conversation, watching TV, and the enjoyment of one's property. These effects have been described in detail in publications by the U.S. Environmental Protection Agency and others referenced here. (See especially EPA, 1973 and 1974; Passchier-Vermeer, 1993; and Suter, 1992a and 1992b.)

It is clear from research conducted over the years that the noise levels to which the neighbors of Sea-Tac are exposed is producing adverse effects now -- effects that will not be allayed by reducing the average overall level by 1.55 dB. DNLs of 65 dB to higher than 75 dB are excessive. Many years ago the U.S. EPA identified a DNL of 55 dB as necessary to protect the population against the unwanted effects of noise (EPA, 1974). Recent research confirms the findings of the earlier investigations relied upon by the EPA that high levels of annoyance are often generated at levels well below the DNL of 65 dB used by the FAA and its consultants (Fidell *et al.*, 1985; Fidell *et al.*, 1991; Hall *et al.*, 1981; Miedema, 1992).

The levels of noise in the environment around Sea-Tac adversely affect the teaching-learning relationship, as most teachers will attest. They lead to what has been called "jet-pause teaching." Studies show that such levels may be expected to cause decrements in children's reading skills, long-term recall, and tolerance for frustration (Bronzaft and McCarthy, 1975; Cohen and Weinstein, 1981; Hygge *et al.*, 1993).

These noise levels are well above the DNL of 45 dB identified by the U.S. EPA to protect against sleep interference (EPA, 1974), as well as the levels recommended by other experts on the effects of noise on sleep (Griefahn, 1990; Eberhardt, 1987 and 1990; Vallet *et al.*, 1976 and 1990). They increase the chances of awakening from sleep and they diminish sleep quality by causing people to shift from heavier to lighter stages of sleep.

With respect to the extra-auditory health effects of noise, no clear dose-response relationships exist at this time, although there is evidence suggesting adverse health effects from high levels of noise in general (Ising and Kruppa, 1993; Peterson *et al.*, 1978, 1981, and 1983; Rehm, 1983) and some evidence implicating aircraft noise in particular (Hygge *et al.*, 1993; Ising and Kruppa, 1993; Knipschild and Oudshoorn, 1977). The current thinking on the subject is that these effects are most likely mediated psychologically, through aversion to noise. This would make it virtually impossible to predict adverse health effects as a function of noise exposure level. The distinct possibility of adverse health effects, does, however, stress the importance of minimizing excessive levels of noise, especially when such factors as preventability and controllability are important contributors.

Summary

It should be clear by now that the performance objectives of the Port of Seattle's Noise Budget and Nighttime Limitations Program will not produce a significant reduction in real noise impact on the community. The predicted decreases in ANEL may not occur because they are within the margin of error of such predictions, but, even if they do, they will most likely be imperceptible to the impacted residents. Decreases in DNL of 1.55 dB (or 2.1 dB) are too small to be noticeable. The statement by the Port's consultant that the noise will be decreased by 30 percent by the year 1996 is misleading, since the ear perceives changes in loudness in much larger increments than the equal energy rule would predict.

The reaction of the community is not likely to change at all between the base year and 1996, and, in fact, may intensify because of the importance of the non-acoustic variables. In the case of Sea-Tac in particular, where there is so much anxiety about the prospect of a third runway and so much skepticism about the responsiveness of the airport authority, non-acoustic factors are destined to play a very important role.

The evidence is also very clear that the use of DNL alone, especially in the form of the Schultz curve, greatly underestimates the adverse reaction of the community. It should only be a matter of time before U.S. scientists discontinue the use of the Schultz curve in its present form for the prediction of community reaction to aircraft noise.

Finally, the Panel must consider that the impact of aircraft noise on the community surrounding Sea-Tac is already excessive. It degrades the quality of teaching and learning, it disrupts sleep, it interferes with the enjoyment of property and the natural surroundings, and it causes undue disturbance for literally thousands of citizens every day. The levels experienced by Sea-Tac's beleaguered neighbors are already 10 dB to nearly 25 dB above those recommended by the EPA to protect the public health and welfare. The approval of a new runway on the basis of the ephemeral and inadequate reductions forecast for 1996, or even for 2001, is ill advised and would most likely have a pernicious effect on the community.

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